This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

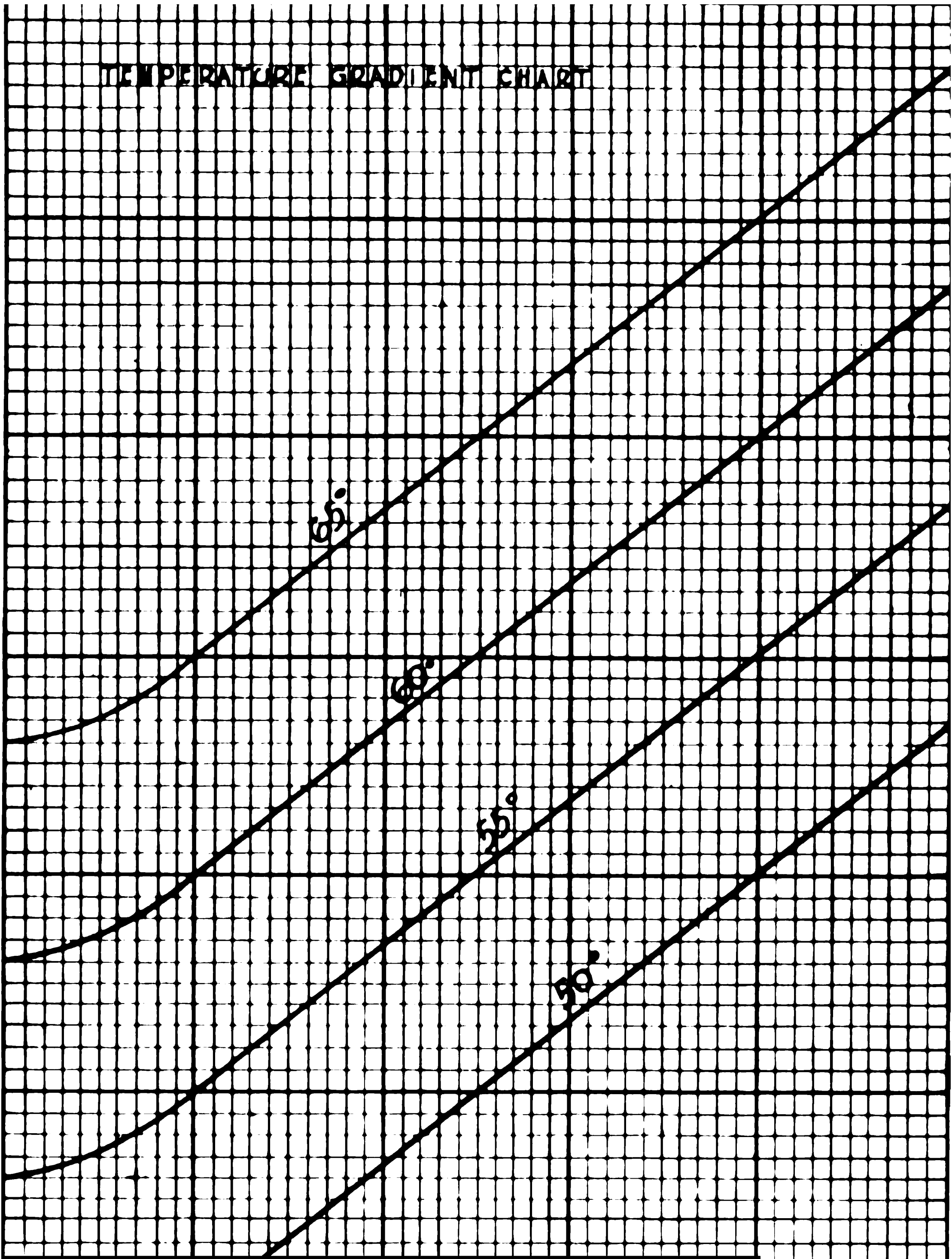
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



The Building Services Engineer

Chartered Institution of Building Services,
Institution of Heating and Ventilating Engineers (Great Britain)

PROPERTY OF
University of
Michigan
Libraries
1817
ARTES SCIENTIA VERITAS

JOURNAL of
THE INSTITUTION OF HEATING & VENTILATING ENGINEERS

1934 — 1935

JOURNAL
VOL. 2

PROCEEDINGS
VOL. 33

Established 1897

The Rights of Publication or Translation Reserved. The Institution as a body is not responsible for the statements made or the opinions expressed in papers read, contributions to discussions or other contributions published in this "Journal."

Published by
The Institution of Heating & Ventilating Engineers
12 RUSSELL SQUARE, LONDON, W.C.1

Engin. Library

TH
7201
.I59
v.2

Printed by Herbert Reiach, Ltd.,
43 Belvedere Road, London, S.E.1.

Gratis
Athenaeum
8·15·35
89647

CONTENTS

Officers for year 1934-35 and Committees
Thirty-fifth Annual Report
Balance Sheet, December 1st, 1933-November 30th, 1934
Mr. R. Comyn Ching, President 1
Ordinary Meeting, London, February 14th, 1934 3
Address by the President 14
Infra-Red Rays and Comfort—*Sir Leonard Hill,* F.R.S., (Hon. Member) . . 20
Discussion 33
Past-Presidents' Luncheon 43
Economy in Factory Heating—*A. F. Dufton,* M.A., D.I.C. 44
Sessional Meeting, London, March 7th, 1934 49
The Prevention of Vibration and Noise in Heating and Ventilating Systems—*Robert B. Grey,* A.M.I.Mech.E., M.Inst.P.T. 50
Discussion 57
Alignment Charts, their Construction and Use—*A. C. Pallot,* B.Sc. (Eng.), M.I.E.E., A.M.I.C.E., A.M.I.Mech.E., (Member) 69
Degree-Days—*A. F. Dufton,* M.A., D.I.C. 83
The Computation of Heat Loss Coefficients—*R. A. Price* (Associate Member) . 93
Domestic Hot-Water Supply for Large Buildings—*F. R. L. White* (Associate Member) 105
Air Conditioning in Industry—*H. W. Hall* (Associate Member) 116
The Kata-Thermometer as Leslie's Anemometer and a Simplified Method for Computing—*A. F. Dufton,* M.A., D.I.C. 123
Natural Ventilation—*F. S. Caink* (Associate Member) 137
Pipe Sizing for Hot and Cold Water Supply Service—*W. E. Fretwell* (Vice-President) 154
Decibels—*A. F. Dufton,* M.A., D.I.C. 172
Summer Special Meeting, Hastings, June 19th, 1934 181
Some Heating and Ventilating Problems—*A. F. Dufton,* M.A., D.I.C. . . . 193
Metallic Wall-paper—*A. F. Dufton,* M.A., D.I.C. 218
Unit Heating Installations—*F. M. Ware* (Associate Member) 225
The Case for the Private Plant—*E. G. Phillips,* M.I.E.E., A.M.I.Mech.E., (Member) 230
Modern Methods of Heat Insulation—*Cyril S. Woodward,* B.Eng., A.M.I.N.A. . 245
The Measurement of Equivalent Temperature—*A. F. Dufton,* M.A., D.I.C. . 256
Syllabus of Examinations 259
The Measurement of Air Velocities by Means of Silvered Kata-Thermometers—*T. Bedford,* Ph.D. and *C. G. Warner,* B.Sc. 269
New Committee 272
Radiant Heat and Comfort—*Harold Hartley,* D.Sc. 273
Modern Methods of Attacking Heat Transmission Problems—*Prof. C. H. Lander,* C.B.E., D.Sc., M.Inst.C.E., M.I.Mech.E. 292
Thermal Precipitation of Dust—*A. F. Dufton,* M.A., D.I.C. 308
Copper and Drinking Water, A Correction 311
Some Problems of Boiler Water Treatment with Particular Reference to Colloidal Conditioning—*George S. Irving,* A.M.I.Chem.E. 317
Gas and Coke-Fired Boilers for Central Heating and Domestic Water Heating—*S. Adams* (Associate Member) 332
Naval Hygiene—*Surgeon-Commander H. St. C. Colson,* M.B., B.Sc., D.P.H. . 343
Rays on the Skin—*A. F. Dufton,* M.A., D.I.C. 345
National Physical Laboratory, 1933 348
Autumn Special Meeting, London, October 9th, 1934 361
Some Recent Improvements in Boiler Plant for Central-Heating and Hot-Water Supply—*F. M. H. Taylor,* Ph.D., B.Sc., A.R.C.S., M.Inst.Fuel, (Member) . 368
Discussion 403, 495
The Warming of Walls—*A. F. Dufton,* M.A., D.I.C. 416, 457
Sessional Meeting, London, November 7th, 1934 421
Metallic Insulation—*G. P. Crowden,* M.Sc., M.R.C.S., L.R.C.P. 422
Discussion 449
Nose-Opening Rays—*Sir Leonard Hill,* M.B., F.R.S. 458

CONTENTS (continued)

The Exclusion of Solar Heat. 1.—Light Roofing Structures—*H. E. Beckett*, B.Sc. 461
Sessional Meeting, London, December 5th, 1934 465
Manufactured Solid Fuel for Heating—*L. J. Fowler*, B.A., A.M.I.C.E., (Member) 466
Discussion 483
The Measurement of the Rate of Air Change—*W. G. Marley*, M.Sc. . . 499
Sessional Meeting, London, January 9th, 1935 509
Air Heaters for Heating, Ventilating and Drying—*A. Fleming Browne*, M.I.Mech.E., (Member) 510
Discussion 527
The Globe Thermometer in Studies of Heating and Ventilation—*T. Bedford*, Ph. D. and *C. G. Warner*, B.Sc. 544
New Books 85, 126, 174, 353, 504
Abstracts 46, 89, 129, 175, 221, 264, 312, 356, 418, 507, 551
Heating and Ventilating Index . 47, 91, 134, 178, 223, 267, 315, 359, 419, 505, 549

AUTHORS

Adams, S. 332
Beckett, H. E. 461
Bedford, T. 269, 544
Browne, A. Fleming 510
Caink, F. S. 137
Ching, R. Comyn 14
Colson, H. St. C. 343
Crowden, G. P. 442
Dufton, A. F. 44, 83, 123, 172, 193 218, 256, 308, 345, 416, 457
Fowler, L. J. 466
Fretwell, W. E. 154
Grey, Robert B. 50
Hall, H. W. 116
Hartley, Harold 273
Hill, Sir Leonard 20, 458
Irving, George S. 317
Lander, C. H. 292
Marley, W. G. 499
Pallot, A. C. 69
Phillips, E. G. 230
Price, R. A. 93
Taylor, F. M. H. 368
Ware, F. M. 225
Warner, C. G. 269, 544
White, F. R. L. 105
Woodward, Cyril S. 245

THE INSTITUTION OF HEATING AND VENTILATING ENGINEERS

OFFICERS—1934-1935

President

R. Comyn Ching	London

Vice-Presidents

W. E. Fretwell	London
A. B. Potterton	London

Past-Presidents, *ex-officio* members of the Council

J. Nelson Russell, M.Amer.Soc.H.V.E.	1902	London
Sir Louis F. Pearson, C.B.E.	1903	Beeston
Geo. Crispin	1905	Bristol
W. Nelson Haden, M.I.Mech.E.	1906/07	Trowbridge
A. Basil Simpson	1908	London
Walter Yates, M.I.Mech.E.	1909	Manchester
C. Ingham Haden, M.I.Mech.E.	1910	Trowbridge
S. Naylor, M.I.Mech.E.	1916/17	Halifax
E. Herring, M.I.Mech.E.	1918/19	London
W. W. Nobbs, M.I.Mech.E.	1920	London
Frank Biggin, M.I.Mech.E.	1921	Sheffield
Arthur H. Barker, B.A., B.Sc., M.I.C.E.	1922	Westminster
John Watson	1923	Westminster
P. M. B. Grenville	1924	London
Alcwyn A. Jones	1925	London
Oswald Stott	1926	London
J. L. Musgrave	1927	London
J. Roger Preston, M.I.Mech.E.	1929	London
E. R. Jones	1930	Stourbridge
Sam Fox, M.I.Mech.E.	1931	Halifax
J. W. Cooling, M.Sc.(Tech.), A.M.I.Mech.E.	1932	London
James Elliott	1933	Manchester

Members of Council in order of election

A. Fleming Browne, M.I.Mech.E.	London
G. Nelson Haden, B.Sc.	London
J. Newman Ellis, B.Sc., A.M.I.C.E.	Manchester
C. R. Allensby, M.I.Mech.E.	London
R. G. Crittall	London
Geo. A. Pullen, M.I.Mar.E.	London
G. L. Copping, A.M.I.Mech.E.	London
Oscar Faber, O.B.E., D.Sc., M.I.C.E.	London
W. S. Holt (Associate Member)	Bolton
J. H. Bryant (Associate Member)	London
J. W. Stitson (Associate Member)	London

Hon. Treasurer

W. Nelson Haden	Trowbridge

Auditors

J. & A. W. Sully & Co., 19 & 21 Queen Victoria Street, London, E.C.4.

Bankers

Barclays Bank Ltd., 9 Russell Square, London, W.C.1.

Secretary

H. B. Watt, 12 Russell Square, London, W.C.1.

Registered Office

12 Russell Square, London, W.C.1.
Telephone: Museum 1381.

LIST OF COMMITTEES

1934—1935

Finance :—The President, Senior Vice-President, W. Nelson Haden (Hon. Treasurer), W. W. Nobbs.

Technical Education:—W. Yates (Chairman), J. W. Cooling, R. C. Ching, Oscar Faber, W. E. Fretwell, Alcwyn A. Jones, J. Roger Preston, G. Nelson Haden, J. H. Bryant (A.M.).

Library :—J. L. Musgrave (Chairman), A. Fleming Browne, Alcwyn A. Jones, John Watson, Sam Fox, H. M. Vernon, J. W. Stitson (A.M.).

Bye-Laws :—W. W. Nobbs (Chairman), J. Newman Ellis, W. Nelson Haden, Alcwyn A. Jones, J. Roger Preston

Publicity :—Alcwyn A. Jones (Chairman), A. Fleming Browne, J. Newman Ellis, Sam Fox, W. E. Fretwell, J. Roger Preston, John Watson, J. W. Stitson (A.M.).

Safety Devices :—Sam Fox (Chairman), J. Newman Ellis, E. R. Jones, S. Naylor, A. B. Potterton, F. Biggin, E. J. Petheram, Co-opted.

Offices Joint Committee :—The President and Ex-President for the time being.

Scrutineers—Membership Proposals:—J. W. Cooling (Chairman), Oscar Faber, Geo. A. Pullen, A. Fleming Browne, The President, Ex-President, and the two Vice-Presidents for the time being, C. R. Allensby, R. G. Crittall, J. H. Bryant (A.M.).

Entrance Examinations Board :—(Elected October 3rd, 1933):—J. W. Cooling, (Chairman), D. Betts, R. C. Ching, G. L. Copping, L. J. Fowler, J. H. Francis, W. E. Fretwell, G. Nelson Haden, Alcwyn A. Jones, W. W. Nobbs, E. L. Oughton, A. C. Pallot. J. Roger Preston, Oswald Stott, John Watson, L. Copeland Watts.

Reception Committee :—J. H. Bryant (A.M.) (Chairman), Geo. Crispin, E. Herring, Harry Merrin, S. Naylor, Geo. A. Pullen, W. S. Holt (A.M.).

Housing Committee :—E. R. Jones (Chairman), Sam Fox, The President, Vice-Presidents and Hon. Treasurer. J. L. Musgrave T. F. C. Potterton, with power to co-opt others.

Research Committee :—W. W. Nobbs (Chairman). W. Nelson Haden, J. L. Musgrave, J. Roger Preston, Sam Fox, C. R. Allensby, R. G. Crittall, Oscar Faber, J. H. Bryant (A.M.), and W. G. Case, W. Mumford Bailey, A. F. Dufton, C. A. Masterman, Co-opted.

Selection Committee :—The President, and the four Past Presidents immediately preceding, and the Hon. Treasurer.

London Building Acts (1930) Amendments Committee :—J. W Cooling (Chairman), W. W. Nobbs, R. C. Ching, G. L. Copping, W. E. Fretwell, J L. Musgrave, J. Roger Preston, J H. Bryant (A.M.).

"Journal" Committee :—Sam Fox (Chairman), Alcwyn A. Jones (Convener), J. W. Cooling, A. Fleming Browne, J. Roger Preston, G. L. Copping, C. R. Allensby, R. G. Crittall, J. H. Bryant (A.M.)

Also co-opted :—W. Nelson Haden (Hon. Treasurer) and W. W. Nobbs.

Negotiating (R.I.B.A.) Committee:—J. W. Cooling (Chairman), Oscar Faber, W. E. Fretwell, G. Nelson Haden, J. L. Musgrave.

Benevolent Fund :—R. C. Ching (Chairman), W. E. Fretwell, W. W. Nobbs (or W. Nelson Haden). A. B. Potterton, and J. H. Bryant (Associate Member).

Minimum Specifications for Heating and Ventilating Materials:—J. W. Cooling (Chairman), Frank Biggin, R. C. Ching, G. L. Copping, W. E. Fretwell, F. H. Horton, J. L. Musgrave.

Associate Members and Graduates Section

London and District :—J. W. Stitson (Chairman), E. B. Darby, W. Ferne, H. J. Knox, H. L. Egerton and J. H. Bryant (Hon. Secretary).

Manchester and District :—J. Newman Ellis (Chairman), J. B. Atherton, W. Atkinson, L. Barton, A. Mayall and W. S. Holt (Hon. Secretary).

Liverpool and District:—A. Holt Lake (Chairman), H. Cockram, John J. Barton, D. J. Sessions, D. Thorpe and M. P Concannon (Hon. Secretary).

Birmingham and District:—E. A. Couzens (Chairman), W. Roy Cox, F. S. Stacey, W. G. Chasser, R. A. Shilston and R. E. Otter (Hon. Secretary)

THE INSTITUTION OF HEATING AND VENTILATING ENGINEERS

PAST PRESIDENTS

John Grundy (*deceased* 1913)	1898
Walter Jones (*deceased* 1924)	1899
D. M. Nesbit (*deceased* 1929)	1900
W. R. Maguire (*deceased* 1923)	1901
J. Nelson Russell	1902
Sir Louis F. Pearson, C.B.E.	1903
Jno. S. Palmer (*deceased* 1909)	1904
Geo. Crispin	1905
W. Nelson Haden	1906
W. Nelson Haden	1907
A. Basil Simpson	1908
Walter Yates	1909
C. Ingham Haden	1910
Oliver M. Row (*deceased* 1926)	1911
Chas. R. Honiball (*deceased* 1932)	1912
J. E. Hartley (*deceased* 1928)	1913
K. Gray	1914
H. H. Grundy (*deceased* 1932)	1915
S. Naylor	1916
S. Naylor	1917
E. Herring	1918
E. Herring	1919
W. W. Nobbs	1920
Frank Biggin	1921
Arthur H. Barker	1922
John Watson	1923
P. M. B. Grenville	1924
Alcwyn A. Jones	1925
Oswald Stott	1926
J. L. Musgrave	1927
S. Booth Horrocks (*deceased* 1931)	1928
J. Roger Preston	1929
E. R. Jones	1930
Sam Fox	1931
J. W. Cooling	1932
James Elliott	1933

JOURNAL *of*
THE INSTITUTION OF
HEATING & VENTILATING
ENGINEERS

Vol. 2. MARCH 1934 No. 13.

R. COMYN CHING

PRESIDENT 1934-35

The new President of the Institution of Heating and Ventilating Engineers, Mr. R. Comyn Ching, was born in 1876 at Bredgar, Sittingbourne, Kent, and educated at the City of London School. On leaving school he attended the Regent Street Polytechnic to further his technical education. At present he is managing director of the firm of Comyn Ching & Co. (London) Ltd., which was established 200 years ago. He joined the Institution in 1917 and has taken an active part in its work and served on a number of committees. Owing to his interest in education it is only natural to find his name appearing on committees dealing with technical education and examinations. Always a busy man yet he gives of his valuable time for the benefit of the industry. He has just completed his Presidency of the National Association of Heating, Ventilating and Domestic Engineering Employers and is chairman of the Joint Industrial Council, of which he was formerly treasurer, and was for five years the chairman of the National Technical Education Committee of the Joint Industrial Council; he has also been chairman of the London Branch of the Employers Association. He is a member of the Advisory Committee of the City and Guilds of London Institute. He has always been actively interested in sports, having played football, cricket and tennis for the Regent Street Polytechnic and still finds time to play golf and tennis. His Presidential Address should be an inspiration to the younger generation and his proposals regarding scholarships and the Benevolent Fund presage further progress in the work of the Institution.

R. COMYN CHING

President 1934-35

INSTITUTION OF HEATING AND VENTILATING ENGINEERS

REPORT

ORDINARY MEETING, LONDON, FEBRUARY 14th, 1934

THE Ordinary Meeting of the Institution was held in the Lecture Theatre of the London School of Hygiene and Tropical Medicine, London, W.C.2, on February 14th, 1934, Mr. James Elliott, Retiring President, in the Chair; afterwards, Mr. R. Comyn Ching, President, presiding.

The following signed the attendance register, and there were also others present: Messrs. H. M. Vernon, G. W. Fowle, E. L. Joselin, L. W. Andrew, A. J. H. Binns, A. Fleming Browne, John Watson, Walter Scott, Alcwyn A. Jones, H. Leslie Egerton, W. A. Young, W. E. Fretwell, E. B. Darby, C. B. Jackson, S. J. Warrell, T. E. Barnes, R. Comyn Ching, Robt. E. Herring, W. H. Dupen, J. H. Bryant, A. B. Potterton, L. Copeland Watts, J. Roger Preston, Louis A. Forni, L. C. C. Rayner, Edgar Herring, J. G. Clark, Geo. A. Pullen, J. W. Cooling, G. W. Martin, Sir Leonard Hill, T. F. C. Potterton, J. Murray Grammer, Harry Merrin, S. Adams, W. G. Case, Oscar Faber, E. G. Brooks, F. Brooks, G. Nelson Haden, C. S. K. Benham, and H. B. Watt (Secretary) (London); James Elliott, Walter Yates, Oswald Stott, J. Newman Ellis (Manchester); Sam Fox, A. S. Naylor, Sam Naylor (Halifax); Herbert J. Fisher (Melksham); Victor N. Smith (West Wickham); Hubert Hill (Bradford); C. E. Ashton (Kenton); W. Mumford Bailey (Thorpe Bay); R. W. Jenkins (Rotherham); Frank Biggin (Sheffield); W. Newbold (Beeston); Frank Moody (Luton); S. Thomson (Hull); C. Ingham Haden (Trowbridge); C. J. Merritt (Shanghai); and the following visitors: C. G. Warner, A. Watt, S. Roberts, Edgar A. Bleach, E. W. Murray, D. Chandler, A. W. Stafford, D. V. Onslow, T. C. Angus, Dr. A. Bradford Hill, H. S. Taylor, Dr. R. H. Rattray, Albion T. Snell, Sir David Munro, A. E. Malone, Dr. G. P. Crowden; Miss M. M. Murray (London); H. E. Beckett, A. F. Dufton, Dr. Bedford (Watford); Dr. William A. R. Thomson (Portsmouth); Miss Nannette Hill (Chalfont St. Peter); T. N. Riley (Radlett).

MINUTES.

The Secretary (Mr. H. B. Watt) read the Minutes of the Autumn Meeting held on October 3rd, 1933, which were confirmed and signed.

ANNUAL REPORT AND BALANCE SHEET.

It was agreed to take the Annual Report of the Council (previously circulated) as read, and it was proposed by *Mr. J. Roger Preston* and seconded by *Mr. A. Fleming Browne* and agreed unanimously that it be received and adopted.

The Retiring President, in putting the above motion, said that it was very encouraging to find that the Institution was not receding in any way, but was gaining ground.

It was also agreed that the Balance Sheet and Statement of Accounts be taken as read.

Mr. W. W. Nobbs then proposed that the Balance Sheet be received and adopted. He said that in the absence of the Treasurer it fell to his lot to present the Accounts, copies of which members had in front of them. The Statement of Accounts showed a credit balance on the year of about £190, and the accumulated fund now stood at about £1,450, which was exclusive of the Capital Account for the Research Fund. The Research Fund at the end of the financial year stood at £782, and that amount had been increased by further donations and now stood at something over £1,000. He was also pleased to report that very shortly that account would be drawn upon, which meant that they were proceeding with the construction of the work for which those contributions were made.

He felt sure that the Honorary Treasurer, had he been present, would have drawn attention to the subject of arrears, and would have pointed out that it was very desirable if the work of the Institution was to continue efficiently that members should pay attention to that important point. There were 70 members of different grades who had not paid their subscription for last year, and there were still 20 subscriptions outstanding for the previous year, and 18 for the year before that. These numbers were not very large for an institution with a membership of more than 900, but he hoped that members who had overlooked the fact that their subscriptions were due would remit promptly. A very pleasant item in connection with the Accounts was that the *Journal*, which was instituted for the convenience of members, had paid its way without any extra cost to the Institution above that formerly paid for the annual volumes. The *Journal* had met with the favourable reception which was anticipated, and members of the Institution now received reports of the meetings monthly instead of having to wait a long period, by which time some of the matter might, from their point of view, have become obsolete.

Mr. E. R. Dolby seconded the adoption of the Balance Sheet, and this was agreed to unanimously.

ELECTION OF NEW MEMBERS.

The Secretary (Mr. H. B. Watt) read a list of candidates for election as Members, Associates, Associate Members and Graduates—27 in all (including 4 transfers). He said that these were recommended for election by the Council after having been scrutinised and passed by the Scrutineers Committee.

MEMBERS: P. W. Alcock, 9 Sunnycroft Road, Western Park, Leicester; T. Gerard Connor, 78 Lewin Road, Streatham, S.W.16; Arthur C. Furner, Jerram & Co. Ltd., Babington Lane, Derby; H. A. Sandford, 23 Bush Lane, London, E.C.4; F. M. H. Taylor, Gas Light and Coke Co., Horseferry Road, S.W.1.

TRANSFERS FROM ASSOCIATE MEMBERS TO MEMBERS: Norris H. Crosland, 16 Highfield Terrace, Cullingworth, Bradford, Yorks; David Peters, 16 Abergele Road, Stanley, Liverpool; Clarence W. Ulett, 44 Church Road, Newport, Mon. (and Air Ministry, London).

ASSOCIATE: Arthur J. Burton, 32a Marlborough Road, Colliers Wood, London, S.W.19.

ASSOCIATE MEMBERS: R. P. Braun, 34 Gerard Road, Harrow, Middlesex; B. P. Brunt, 51 Richmond Road, Rugby; John W. Cowan, "Springfield," 9 Elm Grove Road, Farnborough, Hants; Thos. H. S. Hatchett, 52 Windsor Road, Church End, Finchley, N.3; George W. Jetson, 64 Pargeter Street, Walsall, S. Staffs; William Kerr, 10 Virginia Street, Greenock; Philip G. Matthews, 330 Gillott Road, Edgbaston, Birmingham 16.; Edwin Osborne, C. B. Jackson & Co. Ltd., 7 Hobart Place, Grosvenor Gardens, S.W.1; George B. S. Payton, "Homeway," Squirrels Heath Road, Harold Wood, Essex; Archie Richardson, 111 Ellesmere Road, Sheffield, 4; George A. Rooley, 92 Cambridge Street, Leicester; H. E. Southall, 22 Maple Tree Lane, Cradley, Staffs; T. B. Ward, 41 London Road, Bishops Stortford, Herts.

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER: Leslie Barton, 2 Wilfred Street, Swinton, Manchester.

GRADUATES: G. S. Akinhead, 95 Dinsdale Road, Sandyford, Newcastle-upon-Tyne; Graham Braithwaite, 33 Rosedale Avenue, Great Crosby, Liverpool, 23; Maurice Gatoff, 74 Acanthus Avenue, Fenham, Newcastle-upon-Tyne, 4; Arthur E. Thomas, 32 Orleans Road, Old Swan, Liverpool, 13.

The Retiring President remarked on the fact that it was very gratifying to know that quite a number of associate members had come into the ranks by examination.

Mr. Alcwyn A. Jones moved the election *en bloc* of the candidates whose names had been read out. He said that at the Council meeting held earlier in the day the Scrutineers Committee reported that the whole of these names had been thoroughly examined;

they were also considered by the Council and approved. It was just as well to know that the number elected was not commensurate with the number of applications, which showed that the Institution had a status which enabled it to pick and choose among those who applied for membership.

Mr. Frank Biggin seconded the motion, which was carried unanimously.

ELECTION OF AUDITORS.

Mr. E. L. Joselin moved that the auditors, Messrs. J. & A. W. Sully & Co., Chartered Accountants, be re-appointed at a fee of six guineas.

This was seconded by *Mr. Geo. A. Pullen*, and agreed to.

REPORTS OF COMMITTEES.

Journal Committee.

Mr. Sam Fox said that there was very little for him to report as Chairman of the Journal Committee. The *Journal* was now almost a year old, and he thought it had been accepted by the members as quite a successful production, and members were to be congratulated on its successful first year. Those concerned in its production were aware, of course, that it was not perfect, and at any time they were quite ready to receive suggestions from members for its improvement. He wished it also to be known that the Committee had decided to make as a gift quite a substantial binder, so that any member who desired to do so might have his copies bound therein. The binders could be had on application to the Secretary.

Scrutineers Committee.

Mr. J. W. Cooling reported that the Scrutineers Committee had met three times during the year, and altogether 166 applications had been scrutinised and 91 new members had been admitted to the Institution during that period. Twenty-six of these 91 successful candidates passed the entrance examination. The applications were very carefully scrutinised, the qualifications of the applicants being carefully gone into, and he did not think that any member could complain that the wrong people were being admitted into the Institution. The list which had just been read comprised part of the new members proposed during the session ; others were elected at the Autumn Meeting.

Entrance Examinations.

Mr. John Watson reported that there had been, as usual, three entrance examinations during the Institution year, viz., in May, September and December. In May the candidates were 7 Graduates, 5 of whom passed and 2 failed, and 14 Associate Members, of whom 6 passed and 8 failed. In September there were 2 Graduates, both of whom passed; and 10 Associate Members, 4 of whom passed and 6 failed. In December the Graduates numbered 11, 4 of whom passed and 7 failed; and the Associate Members numbered 7, 5 of whom passed and 2 failed.

Entrance Examinations Board.

Mr. J. W. Cooling, referring to the examinations, said that the Council had decided that the entrance examinations must be stiffened up, and a new Examinations Board had been formed comprising 16 members of the Institution. That Board had already met once and separated into sub-committees. The first work undertaken was to revise the syllabus of the examinations, and before the next examinations were held that syllabus would be published. The work of the Examinations Board would then consist of setting examination questions, and it was hoped that in the future the standard of the examinations of the Institution would be considerably higher in this respect as a result.

Library Committee.

Mr. Alcwyn A. Jones, deputising for Mr. J. L. Musgrave, presented the report of the Library Committee. The chief item of interest to users of the library, he said, was the new bookcase which had been specially constructed to meet the library requirements. The Council had been good enough to authorise the purchase of the bookcase from the funds of the Institution without encroaching on the funds of the Library Committee, and for that the Committee was grateful. During the year a number of technical journals had been bound into volumes in such a form as to be more convenient for users. A number of books had been presented to the library, and he read a list of these presentations with the names of the donors. During the year 56 books were borrowed by members.

The Retiring President said that it was very gratifying to know that the library was extending and that good use had been made of it. He was informed that letters had been sent to the donors of books thanking them for their gifts.

Research Committee.

Mr. W. W. Nobbs reported that Mr. J. Roger Preston and himself, representing the Institution on the Departmental Committee dealing with research, had attended a good many meetings at Watford, and had also had individual conversations with heads of technical sections at Watford. In the Research Committee of the Institution they had considered the suggestions put forward by various departments and also by members of the Committee, with the result that the original design for the controlled weather house at Watford had been very considerably altered, and, in the opinion of the Committee, very much improved. A meeting was held eight or ten days ago attended by representatives of the Institution's Committee and by representatives of the Government Departments concerned in this work, and on that occasion the final plans were approved for the structure which would make a permanent heating laboratory. He wished to express appreciation on behalf of the Committee of the great assistance that had been received from Mr. J. L. Musgrave, who had been most helpful with practical suggestions in forwarding the work in hand. He had also to record that a very handsome contribution had been received from the electrical industry, and there had been co-opted on the Committee technical representatives of the electrical and gas industries who would from time to time give them the benefit of their experience. He had already mentioned when presenting the accounts that the Research Fund stood at a very respectable figure, and that it was expected very shortly to be drawn upon for disbursements, as it was intended to proceed almost immediately with the construction of the house. The result of one practical experiment was being awaited—an experiment which was the outcome of a suggestion by a member of their own Committee—and, subject to things going as they anticipated with this particular experiment, the construction of the house would be put in hand immediately. He hoped by the next meeting to be able to report that the construction had started, and by that time a syllabus of the initial experiments in connection with this work would be drawn up.

The Retiring President said that he desired to add that the Research Committee had really done outstanding work, and their thanks as members were due to the Committee for having tackled the job in the way in which it had been done ; it had not been rushed, and by the very fact of going forward step by step as they had done they would be able to accomplish the " all weather house," to suit the purposes which they had desired.

Publicity Committee.

Mr. Alcwyn A. Jones said that there was little to report since the programme of the session was started. It was regretted that the attendance at the sessional meetings had been considerably reduced, and the Committee was anxious to know from the members what reasons there might be for that falling off in numbers. The Committee, in preparing the programme, made it of suitable size so that members could keep it in their pockets, and the intimations of the meetings were given in the *Journal* every month. Members were urged to read the notices in the *Journal* as soon as they received their copy.

The President stated that the Council that morning had decided to reintroduce the old system of post-card advices to members with regard to forthcoming meetings.

Mr. A. B. Potterton then proposed that the various reports of Committees which had been presented be formally adopted.

Mr. J. Roger Preston seconded this, and it was carried.

ASSOCIATE MEMBERS AND GRADUATES SECTION.

London and District Branch.

Mr. J. H. Bryant, reporting for the London Branch, said that during the present session five meetings had been held and four visits had been made. It was regretted that the usual number of visits and meetings was not possible owing to greater difficulty being experienced in arranging the programme. The attendance had been maintained at a high average at the beginning of the year, but had fallen off towards the end. Mr. J. W. Stitson was re-elected Chairman at the Annual Meeting, and Messrs. E. B. Darby and W. Ferne were elected to fill the vacancies on the committee, caused by the retirement of Messrs. E. D. Hawes and J. M. Botterill.

Manchester and District Branch.

Mr. J. Newman Ellis, Chairman, said that a formal report of the Branch's activities had already been sent in. He would only add that they started the year with a successful dinner, at which about forty were present. They were fortunate in having the President, Mr. J. Elliott, with them on that occasion, as well as the President of the Manchester Society of Architects. Since then quite a number of successful meetings and visits had been arranged. The attendance would undoubtedly have been better if the system of sending out post-cards had not been suspended, and he was glad to hear that it was to be resumed. He believed that one paper would be coming forward to the Council. Apart from that, there were only formalities to report. At the annual meeting of the Branch the following officers were elected: Chairman, Mr. J. Newman Ellis; Committee, Messrs. L. Barton, W. Atkinson, J. B. Atherton, A. Mayall; Hon. Secretary, Mr. W. S. Holt.

Liverpool and District Branch.

The Secretary, in the absence of a Liverpool representative, read a report by the Hon. Secretary, Mr. M. P. Concannon, of the activities of the Liverpool Branch. He said that a very full report had been sent in, from which it appeared that the first year of the Branch had been very successful and the membership of the Branch was 13 Associate Members at the commencement of the session, and during the session three new Associate Members and three new Graduates were elected, making sixteen Associate Members and three Graduates at present. The Chairman, Mr. A. Holt Lake, had been re-elected, and the names of the other members of the committee were Messrs. J. J. Barton, D. J. Sessions, H. Cockram, D. Thorpe and Mr. M. P. Concannon, Hon. Secretary.

Birmingham and District Branch.

The Secretary, again in the absence of the Chairman, Mr. E. A. Couzens, and the Hon. Secretary of the Birmingham Branch, Mr. R. E. Otter, read a report, the chief point of which was that the average attendance at meetings had been twenty and at visits twenty-six. The report also stated that those who had undertaken to do what they could to place the Birmingham Branch on a sound basis were extremely gratified by the way in which the Birmingham members had supported them, but it was believed that the results could be and would be much better next session. The office bearers had all been re-elected for the present year.

PRESENTATION OF BRONZE MEDAL.

The Retiring President presented the Bronze Medal of the Institution to Mr. W. H. Rogers (Associate Member), of London, for the paper which he had read to the London and District Branch entitled "The Practical Side of Ventilation." He congratulated Mr. Rogers, who received the medal amid applause.

AMENDMENT OF BYE-LAWS.

It was agreed that the proposed amendments of Bye-laws 2, 3, 4 and 5 concerning Members, Associates, Associate Members and Graduates, which were proposed by the Council and had been circulated, should be taken as read.

Mr. W. W. Nobbs, in proposing the adoption of the amended Bye-laws, said that a few words of explanation were required. It had been felt by the Council that the time had come for them to stiffen up the qualifications for the various grades of membership, and as he was chairman of the committee which drew up the Bye-laws as now printed, this work was delegated to him and his committee. The conditions respecting the different grades of membership had been brought more into conformity with the growing size and dignity of the Institution. With regard to Members, the alteration resolved itself primarily into raising the number of years in which an applicant for membership must have had experience in a position of superior responsibility. Originally this term was three years, it had now been increased to five. For the sake of brevity, sub-clauses (*a*) and (*b*) had been joined into one clause, and with regard to Associates the qualifying age had been raised from 25 to 30 years, and similarly with Associate Members. With regard to Bye-law No. 5 dealing with Graduates, it had been felt that even an Operative Member should be required to show some qualifications other than being merely an operative, and it was proposed accordingly that he should pass an examination which would be graded, of course, to the desired educational standard of such candidates.

He then formally proposed :—

"That the amended Bye-laws Nos. 2, 3, 4 and 5 as approved by the Council of the Institution, be adopted."

Mr. E. R. Dolby seconded.

Mr. L. Copeland Watts took exception to the word used in the amended Bye-law No. 2, "eminence," which he thought should be qualified in some way. It had read previously, "eminence in the profession," but as it now read it might mean that eminence in any form would entitle to membership. With regard to "Associate Members," he noticed in the second clause a reference to the qualification of the City and Guilds Institute, and he thought some word, such as "certificate" or "diploma" had been omitted. It occurred under sub-paragraph (*c*), and he thought it should be made clear that a certificate or diploma of the City and Guilds Institute was required.

Mr. W. W. Nobbs, in reply, said that the Committee and the Council had discussed the first point raised by Mr. Watts, but the Council had felt that it ought to be trusted to use the rather wider discretion which was imported into the amended Bye-law. There were cases where it might be argued by someone with a legal mind that a person whom the Institution desired to honour by membership could not be admitted because, although eminent, he had not qualifications in a particular engineering sense. He noted the second point raised by Mr. Watts, and would bring it before the Committee.

Mr. J. W. Cooling, with regard to this same point, said that surely a certificate was issued to every successful candidate in the City and Guilds Institute examination, so that it was unnecessary to use those words in the Bye-law. At the same time there was no objection to including it.

The proposal to adopt the amended Bye-laws was put and carried unanimously.

INDUCTION OF PRESIDENT-ELECT.

Mr. James Elliott, the Retiring President, then vacated the chair in favour of his successor in the presidency, Mr. R. Comyn Ching. In doing so, and in investing Mr. Ching with the badge of office he said that the new President became a member of the Institution in the year 1917, and had taken a very active interest in it. He was elected a member of the Council in 1929, and his knowledge and experience had been extremely valuable, not only to the

Council, but also to the members of the committees with which he had been associated. He ventured to say that the Institution must be highly congratulated on securing the services of Mr. Ching as its President. Apart from his distinguished association with that Institution, Mr. Ching had the honour to be President of the National Association of Heating, Ventilating and Domestic Engineering Employers. If he might say so, Mr. Ching was upholding the traditions of that office with great personal credit. Mr. Ching was also a member of the National Joint Industrial Council, and took a full share of the responsibilities that he was called upon to assume. He had been chairman, not only of the Council itself, but also of its Education Committee, and his services, particularly in matters of technical education, were acknowledged to have been of great value. He hoped that Mr. Ching would have a very successful year of office in the presidency of the Institution.

Mr. R. Comyn Ching, who was received with warm acclamations, said that it was with a great deal of diffidence that he had taken up the office of President for the ensuing year. He fully recognised the great responsibilities that the office entailed. He succeeded an array of Past-Presidents whose excellences made it extremely difficult for anyone to follow them. He thanked all the members for the great honour they had conferred upon him in electing him as their President, and said that he would do his utmost to uphold the Institution and further its interests.

VOTE OF THANKS TO THE RETIRING PRESIDENT.

Mr. R. Comyn Ching next performed what he said was the pleasing duty of presenting to Mr. James Elliott a replica of the President's badge. The distinction, he said, had been well earned, as he was sure all would agree. Mr. Elliott had been one of their best Presidents. He had given unstintingly of his time to the furtherance of the objects of the Institution. During his term of office he had, he believed, travelled something over 5,000 miles to attend the meetings, and he had been most assiduous in his attention to his duties. He would wear the badge next to the one which he already carried as a Past-President of the Employers' Association. It had been his own pleasure to follow in Mr. Elliott's footsteps through most of the chief offices connected with their industry—as Chairman of the Joint Industrial Council, as President of the Association of Employers, and now as President of the Institution. He could not possibly find a better example, and if he could only emulate Mr. Elliott in his zeal and efficiency he would have every hope of concluding his year of office to general satisfaction.

Mr. James Elliott, in expressing thanks for the Past-President's badge, which he said would always bring back to him recollections of his happy term of office, said that it had been his single aim and purpose to make his presidency a useful one. Should it be considered a successful one, honours must be divided. He was proud to have had the most generous support of his colleagues, and he wished to pay a tribute to the immediate Past-President at the time of his own induction, namely, Mr. J. W. Cooling, who had given him unlimited assistance in the early days of his tenure of office. He wished also to thank the members of the Council who had given him every encouragement ; the Vice-Presidents, who could not have undertaken their duties better ; the authors of the papers, who had made their meetings so interesting, and, finally, Mr. H. B. Watt, the Secretary, and his clerical staff, who had done their best to make his term of office run its course so smoothly. To them all he tendered his sincerest thanks.

The President then read his Presidential Address.

DATES OF FUTURE MEETINGS.

The President, Mr. R. C. Ching, said that it had been provisionally decided to hold the Summer Meeting at Hastings. The meeting the previous year was held in North Wales, and it was felt that it was time they came South. The business would really start on Monday, June 18th, but the principal meetings would be held the following day. On the Wednesday it was hoped to have the usual President's Luncheon. The Autumn Meeting was proposed to be held on Tuesday, October 9th, in London, and the Annual Meeting on February 13th, 1935, also in London. A suggestion had been made in the Council that some of the sessional meetings might be held at other centres than London to enable country members in their particular districts to have a better chance of attending the meetings. London, however, was so comparatively easy to reach from all parts of the country that it would probably still be the centre for sessional meetings.

Sir Leonard Hill, who was introduced by the President as one whose previous papers to the Institution had proved of very great value to the members, read his paper on " Infra-Red Rays and Comfort," and with the help of Dr. Rattray, carried out a demonstration.

ADDRESS BY THE PRESIDENT

R. COMYN CHING, ESQ.

ORDINARY MEETING, LONDON, FEBRUARY 14th, 1934

GENTLEMEN : On looking up past Presidential addresses I notice it is usual for the President to express his thanks to members on his election. Believe me, this is no matter merely of form. To be elected President of this, our Institution, is, in my opinion, the highest honour to which any heating or ventilating engineer can aspire, and I do most sincerely thank you for the honour you have conferred upon me.

I am afraid that in one respect I am at a disadvantage, as for a month to come I shall be occupying the Presidential Chair of both the National Association of Employers, and the Institution, but on March 14th next I shall cease to think commercially and shall think scientifically ; though I hope my commercial training may not be entirely wasted.

I believe it was Lord Haldane who said that one of the greatest needs, in his day, was " to think clearly " and I commend this particularly to the young engineer who is up against a problem, whether commercial or technical. Marshal your facts and data, place them on paper if possible—then by a process of elimination discard those which are not material. Get down to those that count and think clearly through them until the problem is solved.

When one is approaching the three-score years, and realises that the allotted span is only ten years more, the inclination is sometimes to look backwards, and on doing so one realises that the pleasures in life do not come so much by thinking commercially, but by finding an ideal and working for its advancement. What better ideal can we have than the advancement of the science of heating and ventilating? Our Institution has done great work for this ideal and there is still much—particularly for the younger generation—to do, in fostering education, in bringing forward new ideas, sifting these by discussion and tabulating the data.

In my younger days I absorbed some of the gospel of work from such writers as Ruskin and Thomas Carlyle, and I would like to give you a quotation from the latter. " There is a perennial nobleness and even sacredness in work. Were he ever so benighted, forgetful of his high calling, there is always hope in a man that actually and earnestly works. All true work is sacred ; in all true work, were it but true hand labour there is something of divinity. Sweat of the brow, sweat of the brain, sweat of the heart, up to that ' agony of bloody sweat ' which men have called divine."

We who are engaged daily in work connected with the rapidly growing science of heating and ventilating have a wonderful opportunity, and I want to engender in your minds a real love for this work, a feeling that you will unselfishly do all in your power to advance its progress, and in this we have a sterling lead through the work of our Institution. I want you to look up to it as your Alma Mater, with a love—almost a reverence—which many of us have for our old School, and a determination to do what lies in our power to uphold its traditions and to further its interests.

The depression through which we have passed during the last two years (now rapidly passing away) has made me think seriously of the hardships endured, particularly by some of our younger members; those who have given much of their own time and hard work to obtain a good grounding in our science, and been thrown out of employment or on short time through fluctuations in trade, which will at periods undoubtedly recur. I am most anxious, therefore, to see our Benevolent Fund firmly established during the period of " plenty " which I hope is in front of us, so that we shall have in hand funds to assist those in need when the time comes. If all our members will join and subscribe, and if those who can will now give a donation, the success of this Fund will be assured.

It is very encouraging to see our membership increasing; in 1926 it was 595, this year 914—an average yearly increase of 45, and our immediate Past-President, Mr. James Elliott, whose steps of rectitude I have so closely followed in the Chairmanship of the Joint Industrial Council, and Presidency of the Employers Association, must be congratulated on 43 new members, in spite of the depression during his year of office. If all our members will act as missionaries, and the status of our Institution is such that all engaged in the industry should surely join, then we may hope to top the 1,000 mark, at any rate during the year of my immediate successor.

I would like to make special reference to our new monthly *Journal*, which I am sure you will all agree, has been most excellently produced. It is a credit to our Institution and is undoubtedly of great value, particularly to many of our country members who cannot get to London to hear papers read and discussed, that they get these in their *Journals* within a month or six weeks instead of waiting nearly a year as was necessary when we had only our annual Proceedings. Our warmest thanks are due to Mr. Sam Fox, the originator and Father of the *Journal*, Mr. Alcwyn Jones, our Editor, and Mr. Watt, whose work for it commercially has been so successful, in that we shall get all the advantages of the *Journal* with a less cost than hitherto on the funds of the Institution.

Our science has a great future before it, our research work should be more closely linked up with our brethren in the medical profession, for heating and ventilation can, and does, do much to improve the health and well-being of our citizens, enabling them to produce more and better work, and it is up to our professors in medicine and hygiene to give us a standard of the results which they wish us to attain. When these are settled perhaps by some process similar to that adopted by the British Standards Institution, on which enquiry we would, I am sure, be pleased to serve, a definite standard for the various classes of buildings could be tabulated and recognised.

I here throw out a suggestion—which is entirely personal and unofficial. Would it be possible to form a strong committee or panel for this purpose, on which should sit members of the medical and architectural professions, also fuel experts, together with members of our and other institutions—selected for their knowledge of the particular type of heating or ventilation in which they specialise, and having the use of our Research Department and All-Weather house to conduct experimental work which would almost certainly be needed? It may be that the Ministry of Health would "father" such an enquiry, for it is of vital importance to the health of the nation and would be of great assistance to county and borough architects and engineers, and probably in the long run effect savings in rates and income tax. I recognise that such an enquiry might last even for some years and the findings would need to be published in sections, for data would have to be collected from existing buildings and plants and tabulated for comparison with expert knowledge of conditions. One sees from articles, data and letters in the technical press vital differences of opinion with regard to methods of heating hospitals, schools and public buildings, the kind of fuel to use and the method of burning same, and it must cause officials responsible many anxious hours to select—I am afraid sometimes the *wrong* system. I feel that a Ministry grant of funds for such an enquiry would be money well spent and be repaid a hundredfold.

In conclusion, it is likely to be a hard and sometimes a trying and difficult road which the young engineer has before him, and though he has at hand to guide him much data which was unthought of in my young days, there are many problems still unsolved, to mention only one—the quantity of natural air interchange in buildings. Our science is altering almost from day to day and vital decisions have to be made, such as whether the heat source shall be coal or coke, and how stoked—or oil, creosote, gas or electricity, and the form of heat, whether mainly radiant or mainly convected, and how it shall be applied and measured. Success is coming to those who in their young days, for that is the time when education is easily absorbed, get a thorough grounding in science, physics, mathematics and drawing, and carry on their studies to pass our Institution examinations—which, by the way, thanks to the new Examinations Board, are likely to be much more searching. There must be within the minds of many of my listeners the seeds of new inventions, which need the training I have mentioned to sift and bring them to practical utility, and I hope our new Research Committee and their All-Weather house will be used and be of great value to individual members as it will be undoubtedly to our Institution as a whole.

If by my words to-day I have been able to ignite some sparks, if not flames, of enthusiasm for this work I am more than satisfied.

The question of a Benevolent Fund has not yet come before a general meeting, or at least not in an official form. I do not propose to bring it as such before this meeting, but only to make a reference to it. The matter was discussed a good many months ago in our Council, and the Council appointed a small sub-committee, consisting mainly of our Finance Committee, to look into the matter generally and to report again to the Council, as to whether they thought that a Benevolent Fund was one which should be fostered and brought forward as part of the Institution or, rather, as an adjunct thereto. The sub-committee reported that they considered it was a matter which should be fostered by the Institution. Another committee was then formed and had also considered the matter very carefully. It was thought that it would be better to have the project in the form of an incorporated benevolent fund—that is, a fund, almost a company, similar in some respects to a limited liability company, but having special permission to omit the word "limited." It would be in that respect on very similar lines to the Benevolent Fund of the Institution of Mechanical Engineers, which is an incorporated society.

The matter was considered at some length again at the Council meeting. It was felt that we could seek and pay for expert or legal opinion with regard to this; that if and when a benevolent fund is formed it is likely to be a matter of some considerable importance, and to last, we hope, for a very long time, after all of us who are here have passed away. It is, therefore, of first importance that it should be drawn up in a proper and legal way, so that the rules and regulations which govern it may have a permanent character and not need much, if any, of revision. It is a matter which I have very much at heart. I feel that our Institution should have a fund of this sort. Most of the other large scientific institutions, such as the Institutions of Mechanical and of Electrical Engineers, have such a fund, and I do feel that it is up to us to have a fund whereby we may help those of our members who are in distress of any kind. Most of the distress, as you know, comes about through misfortune, of a kind not possible to be controlled by those who sustain it. We should be doing the right thing to have a fund by which we can help those who are in distress. I want it to be understood that this is not in any sense a pension fund, but a fund only to be applied for the benefit of actual members of the Institution, of whatever grade, and whether they themselves are subscribers to the fund or not. They will have no legal right, however, to demand pension or any assistance from the fund ; the fund will be governed by a Committee of Management, of which it is proposed that the President for the time being should be chairman. This body will have regular meetings, and the rules and regulations will be very carefully drawn up. The fund will be distributed at the discretion of the Committee of Management, which committee will also be empowered to transfer from the current account any surplus which they think advisable to the capital account of the fund, the capital being invested in some trustee security,and its interest available, together with regular subscriptions, as income to the fund for disbursement as and when required. It would be possible also, perhaps, if the regulations are approved, to transfer from the capital account to income under very careful regulations, though this could only be done by an Extraordinary General Meeting, and by endorsement by a second General Meeting called for the purpose.

Very briefly, therefore, I have disclosed to you the nature of this fund. We hope that at the next Council meeting we shall have the formal rules and regulations properly drawn up to be submitted to the members of the council, and that those rules and regulations will be passed and brought before the next General Meeting, when the fund will become in fact the fund of the Institution. I commend this to your consideration, because I think it will be of very great value.

There is one other matter to which I should like to make reference. The Council had considered the foundation of a scholarship for the purpose of enabling more, particularly the Operative Member, to pass on to the full study of the whole of the technicalities of heating and ventilating. The idea is to create quite a small scholarship—it may be £5, but that matter will be referred to our Education Committee—for the purpose of paying the Operative Member's class fees and helping him in some small way with the cost of travelling from his home to attend lectures. I do feel—and I think our Committee also feel—that it would be good to have some method by which the teaching in the technical education of the operative student was more closely connected with the work of this Institution and with the rather higher standard of examination which the Institution now requires. We had certain examinations and standards under the City and Guilds of London Institute which have now been revised to some extent in this respect, that we found the standard was a little too high for the operative student. We have, therefore, revised the syllabus for the operative student, somewhat lowering the standard of the examination. At the same time we have, under the City and Guilds Institute, constituted another examination intended particularly for those who are able to take an examination embodying more of the detailed data, formulæ, and so on, required by those who are engaged in the design of heating and ventilating appliances. I feel that we ought to have a link between the operative student and the other, and that such a scholarship would furnish that link, that if a boy sets out from the start really to master the whole of the technicalities required in connection with heating and ventilation, and having in view the possibility that he might attain a scholarship later on which would enable him to carry on his studies and to pass our examination, it would be a very good thing for the Institution to be able to give such a scholarship. It is more than probable that the Joint Industrial Council may give from their funds a scholarship of that kind, but I think it would be advantageous for the Institution if it were able also to do the same.

VOTE OF THANKS TO THE PRESIDENT.

Mr. W. W. Nobbs, in proposing the vote of thanks to the President for his Address, said that all the members would agree with him that the Address illustrated the thoughtfulness and care which Mr. Ching exercised in everything he undertook. He personally had been very much impressed with the Address, and he knew that a sincere vote of thanks would be very heartily accorded.

The vote of thanks was passed by acclamation, and was briefly acknowledged by the President.

INFRA-RED RAYS AND COMFORT

By SIR LEONARD HILL, F.R.S., (Hon. Member)

ORDINARY MEETING, LONDON, FEBRUARY 14th, 1934

THE fear of cold is deeply rooted in people's minds because of the chilly feelings which usher in attacks of infectious disease. People fear catching lobar pneumonia through exposure to cold, and yet this disease is practically unknown in sanitoria where patients coming from stuffy homes are given open-air treatment, and this without any preliminary period of acclimatisation : moreover, in U.S.A., where central heating is pushed to extremes, the death-rate from pneumonia has not fallen, while that of other chief diseases has been lowered notably.

Colds in the head occur in sanitoria, but only in small epidemics and when infection is introduced from without. So outbreaks of colds only occur in the chilly climate of Spitzbergen when the population is infected by the arrival of a ship.

Bronchitis is no more frequent a sequela, and takes no longer for recovery, in patients placed in open-air wards where the cooling power is very high, than in patients nursed in warm rooms.

It is rare for any of the infections spread by "droplets" of saliva and exhaled in sneezing, coughing, and explosively speaking, to gain more than a very small footing in sanatoria. Thus during an epidemic of influenza only 1 per cent. of the patients may be affected, against 75 per cent. of the staff. We know that the spread in barracks of cerebro-spinal fever is prevented by ample ventilation and so too with diphtheria in Naval Schools.

Old standards of ventilation required that the air of a room of 1,000 cu. ft. air space should be changed three times an hour. Now, air moving at 1.5 to 3.5 ft. per sec., may, according to the temperature, just cause a sensation of draught, and such movement would change the room air at least one hundred times an hour. It is such ventilation which benefits infections of the respiratory tract, and induces sleep and promotes appetite. With such ventilation tuberculous patients thrive and get well.

Sanatorium medical officers have no doubt, then, that abundant ventilation is far better than the maintenance of a uniform level of temperature. They know that they can keep their patients warm with clothes, hot bottles and food.

We are told by the medical officers of fever hospitals that cases of measles and whooping cough are put with advantage on open-air balconies except when the wind is bitterly cold, and that the best means of preventing streptococcal infections from becoming chronic is open-air treatment. Cases of pneumonia do best in the open air. Rheumatic fever is best treated at first in freely ventilated and moderately warmed wards and then, during the recovery stage, on open-air verandahs. It is only those suffering from surgical shock and the old and very feeble who require to be treated in warm rooms. Medical officers agree that steam heating and high-pressure water heating give stuffy conditions and should not be used in hospital wards. Low-temperature heating by coils or panels with open-window cross-ventilation, on the other hand, afford good conditions. Vernon found that a room heated by ceiling panels to 55° F. gave the same feeling of warmth as one heated to 65° F. by convection.

To secure comfort the loss of body heat by radiation from the skin must be suitably lessened ; it is on radiant heat that the pleasant sensations of open fires depend.

In the House of Commons warm air is impelled through slits in the floor, and drawn out through holes in the ceiling. The movement of air at the inlets tends to make the feet of the members colder than their heads. Some of these complain of the system, and others say it is good. In 1913 the author found that the system congested and restricted the nasal airway, in people sensitive, like himself, and that the shutting up of the floor inlets, and introduction of air at the gallery level, produced comfortable conditions. Some hate to be shut in heated railway carriages, others like the conditions therein. People with catarrhal noses and sensitive to the quality of radiation may form one class, and wide-nosed people with less sensitive skins the other class.

When the author introduced the kata-thermometer as a measure of comfort he suggested that a dry kata cooling power of 5-6 should be maintained in rooms in this country, as this reading was found to be usual when the air felt pleasantly fresh. Now it takes a dry kata cooling power of over 12 to increase the heat production of a subject who is sitting at rest and is dressed in ordinary clothing. The good effects of open-air treatment no doubt depend in part on cooling powers over 12 and the consequent increase of body heat production, and so of appetite, but such occurs only when the movement of air out of doors raises the kata cooling power above 12. It follows that the feeling of freshness indoors, secured at lower cooling powers, depends on sensory excitations of the skin. A cold wind makes the nose run and the eyes water. To keep the conjunctiva of the eye and the respiratory membrane warm more arterial blood must flow through these parts. There is, too, far more secretion owing to greater evaporation, for cold air contains little water vapour compared with air saturated in the lungs and breathed out almost at body temperature. The secretion is highly bactericidal. In the greater flow of blood and secretion lies one of the benefits of open-air treatment.

To secure this benefit people should live in well-ventilated cool rooms, and sleep with windows open.

We know that stuffy feeling felt by many people in heated and crowded rooms are not caused by chemical impurity of the air. The immediate relief afforded by a fan shows that the discomfort is caused by skin sensations.

It has been suggested, however, that there is some unknown cause of stuffiness, and by some this has been attributed to a change in the ionisation of the air.

We know that the ionic content of both outdoor and indoor air undergoes great diurnal and seasonal variations. Thus air may contain from 50 to 800 ions per c.c. In occupied rooms there is a marked decrease in the number of both positive and negative ions, regardless of the type of ventilation. The normal ionic content is not restored until after the occupants leave the room. Yaglou, Brandt and Benjamin investigated the physiological effects of artificially ionised air ; positive or negative ions being added to the number of 5,000 to 1,500,000 per c.c. There seemed to be an appreciable freshness in negatively ionised air, but the conclusion was reached that nothing definite was found to justify the use of artificial ionisation in general ventilation. Brandt also found that the breathing of artificially de-ionised air for a period of one hour had no apparent effect on a subject when put under conditions for studying basal metabolism.*

Stuffiness is produced by passing air through the layers of cotton-wool, which are used as a fog filter in certain plenum systems of ventilation, such as that installed in the House of Commons, and this stuffiness has been attributed to de-ionisation of the air. The author was able to show, however, that the wool filter enormously reduced the velocity and cooling power of the air, and that the lack of cooling was the cause of stuffiness. A room may feel stuffy to one who enters it at a time when little or no alteration in "ions" can have taken place. No difference is felt on breathing ionised air from a container containing radio-active water. In a room fitted with a very large Wimshurst electrical machine the author found that stuffiness produced in him by a dull red, or dark source of heat was relieved by the cooling effect of the draught of air produced by the discs of the machine, when these were set in motion. When the draught was screened off from the face there was no evidence that the ionised air in the room had any effect in relieving the stuffy feelings. Sitting in an insulated chair, with one pole of the machine connected to it, the hair stood on end on the electrification of the body, but there was no relief of the stuffiness produced by such sources of heat.

---

* Yaglou, C. P., Brandt, A. D., and Benjamin, L. C., *Journ. Industr. Hygiene*, 1933, *15* 341. Brandt, A. D., *Journ. Industr. Hygiene*, 1933, *15*, 354.

Sonne* showed that the red and shortest infra-red rays penetrate deeper and so warm the surface of the skin less and the deeper parts more than is the case with the somewhat longer infra-red rays. When an incandescent lamp was the source, the temperature in the derma might be raised to 47½° C. While in the case of a source of longer infra-red rays the temperature had reached only 42° C. when the surface became unbearably hot. Argyll Campbell and the author† confirmed these results, also Dorno, who used the sun as the source. There are nerve-endings in the epidermis among the living cells beneath the horny layer, and other nerve-endings in the derma. When flushing and transudation and evaporation of water are produced by excitation of some of these nerve-endings, the absorbed radiant heat is removed. Owing to their exciting less of such reactions, sources of dull red and dark heat, when close up to the face, give a dry, drawn and prickling sensation. On the other hand, an incandescent lamp, although affording greater energy when brought as close as possible to the face, produces a genial sensation of warmth, and particularly so if a glass screen be held between the lamp and the skin; this to absorb the long or infra-red rays emitted by the hot surface of the bulb. Many people feel a sensation of relief at the moment when such an incandescent lamp is switched onto the face, which is being irradiated with a dull-red source. Although the total energy of irradiation is thus increased, they say "it feels cooler." The warmth of the sun on a day with a cool breeze feels most genial, and on the cliff edge exposed to loss by radiation to the cold sea, and to a sea breeze, one also feels braced. Be it noted that the sensations change at once on stepping into a greenhouse. The invisible and short infra-red rays of the sun penetrate through the glass, and are absorbed by the objects in the house, which in their turn give off dark heat rays. These rays do not penetrate glass. The glass itself becomes heated and this helps to prevent loss of radiant heat. Owing to the infra-red rays and the absence of cooling breeze the greenhouse feels stuffy. In the author's case the airway of his left nostril is closed by such conditions. The wing of this nostril nearly touches the septum of the nose, but leaves a passage wide enough for quiet respiration under good conditions of ventilation. Any congestion of the respiratory membrane sensibly restricts, or closes, this passage. The place of closure is shown by the fact that pulling the wing of the nostril outwards at once opens the airway. This airway is well open out of doors on a sunny day, but it closes when a sheet of glass is held between the sun and the face. On a cold frosty winter afternoon the nose kept closed up to the moment when the sun set behind a hill, the closure occurred when screens of plate-glass, ice and cellophane were used, but not when a screen both of glass and cellophane were held between the sun and the face. These surprising effects were produced reflexly from the skin, and under conditions when the sun produced no sensible feeling of warmth.

---

* Acta Med. Scandinavia 1921, *192*, 54, 335, 394.

† *Lancet*, 1923, 1, 746.

A screen of glass no less changes from nose-opening into nose-closing the effects of the rays from a long-flamed arc, but not in the case of a mercury vapour arc-lamp. When a sheet of glass is held in front of an incandescent lamp, the airway of the author's left nostril remains open, until the face is brought close to the lamp. These effects are found to hold good for others when the nasal airway is first restricted by a screw nose-clip.

Dull red sources at a distance act as nose-closers, and in their case the screen of glass acts as a protector, that is until the face is brought close to the source. There are many evidences of the importance to health of the normal balance of the sun's rays. Thus chilblains are not relieved by irradiation with dull-red or dark sources; in fact, these only help to cause them. The headmaster of a large boarding school told the author that chilblains ceased to occur among the boys one winter after the hot-water pipe system had broken down. There is no better treatment for chilblains than irradiation with arc-lamps, and such lamps are most useful for treating septic wounds, boils, and many other skin troubles. The shortest rays of the sun, in the ultra-violet region, have very little power of penetrating the epidermis, but these rays are powerful to produce sunburn, and all those beneficial reactions which result from ultra-violet ray treatment, including the production of Vitamin D from a fatty constituent of the skin. This vitamin protects children from rickets, and all the infective troubles which attend this crippling disease. We cut out the beneficial rays by coal-smoke, walls, glass windows and clothes and thus rickets prevails in spite of knowledge of its cause. The monkeys, tropical birds, reptiles, etc., at the Zoo are greatly benefited by irradiation with incandescent lamps. Breeding in many animals is so stimulated.

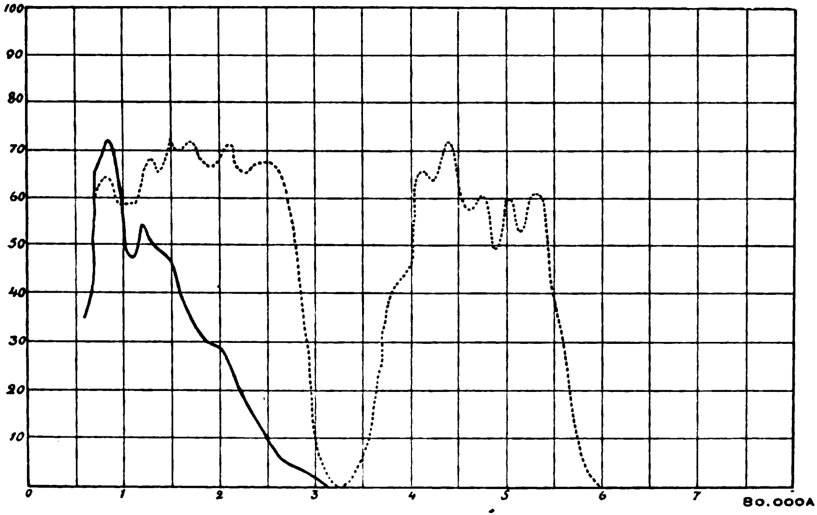
It has already been pointed out that there is greater comfort from the short penetrative rays, which excite flushing and transpiration, than from the longer infra-red rays of low penetrancy.

Fig. 1 shows the penetration of the dry desquamated horny layer of the skin as worked out by my physicist colleague, Dr. H. J. Taylor. This layer has a high absorptive capacity for radiant energy of wave-lengths from 3μ to 3.5μ and for wave-lengths beyond 6μ.

It was shown in the laboratories of Radiation, Ltd. that on subjecting the flexor side of the forearm to an overdose of radiant heat, the intense pain may be suddenly relieved when sweating breaks out at the exposed surface.* The water reflects and absorbs the rays while evaporation cools the skin. Through excitation of the nerves which provoke flushing and sweating there thus results a pleasant moist warm skin in place of a dry burning one. It was found that a preliminary excitation of flushing produced by gentle slapping of the arm, allowed a more prolonged exposure to a high intensity of radiant heat to be endured. On the other hand, a restriction of blood flow induced by an injection of adrenalin, lessened the ability to withstand the heat.

---

* Radiant Heat and Comfort. Part 2, p. 6. Publ. by Radiation Ltd.



—— = Transmission of rat skin (dried).

······ = Transmission of horny layer of skin with electric fire as source.

FIG. 1.

We know that different solids heated electrically emit markedly different qualities of radiant energy. By surface treatment of a refractory gas-mantle with specific catalysing materials, the percentage of the rays emitted by a clinical gas-lamp, which penetrate a screen of clarified horn ⅜ mm. thick was increased from 7½ to 12 per cent. By employing luminous gas-flames in a cobble "Beam" fire, a deep incandescent bed was produced with no glare, and the percentage of penetrating rays raised to 15 per cent. The overhanging upper brick of this fire projected its heat onto the floor, and not on the face. As the result this fire gave a very pleasant sensation of warmth quite different from the heat emitted by a dull-red source. Such a source not only emits rays which feel unpleasant, but closes the airway of the author's left nostril. The putting of a dull-red electric fire under a wide open flue, did not afford any relief to the nose-closing rays, but a screen was at once protective. The author cut a hole in a screen of cardboard just big enough to push the nose through for breathing the hot air when close up to the electric fire. This had no closing effect, but the moment the screen was removed, and the rays acted on the skin, closure occurred.

To demonstrate the closing effect a celluloid mask was used which covered the nose and mouth. A rubber cushion formed the rim of the mask and secured its air-tight application, the cushion was carried across the middle of the mask so as to divide it into a nasal and a mouth-breathing portion. The opening into the mouth-breathing portion was kept closed, so that breathing through the mouth was impossible. The opening into the nasal portion was so restricted that breathing through both nostrils was just adequate. The pressure of the rubber cushion against the sides of the nose, of itself tended to restrict the airway—the conditions were thus made as favourable as possible for testing nose-closing rays. A side tube connected the nasal portion of the mask to a coloured water manometer, and the oscillations of the meniscus sufficed to indicate the breathing to an audience. On facing an electric fire or any other dull-red or black source the nasal breathing of the author under these conditions becomes totally obstructed. Another way of demonstration was to arrange the size of the inlet of this mask so that the air supply sufficed to enable one to step up and down from a footstool eight inches high, in time with every other stroke of a metronome set to beat seconds. To continue the stepping soon became impossible when the electric fire irradiated the face.

The sensitivity of the author to the rays is great. He is influenced 20 ft. or more away from the fire in a closed and otherwise unheated room. The sensitivity is much less when the body feels chilly; cooling the skin by fanning, or approximation of a cold surface, or by wetting at once opens the nose. Breathing through the mouth also opens the nose temporarily. A flaming open coal fire does not close the nose, but the rays from the hot surroundings do when the flame is screened off from the face.

Similarly, the flaming radiants of a gas-fire do not cause nose-closing, but the rays from the hot firebrick above do when the flaming part is screened off the face. Radiation Ltd. have just contrived a new "super-Beam" gas-fire wherein the firebrick is replaced by radiants. This fire does not close the author's nose.

Screens of cellophane, gelatine and desquamated horny layer of skin, also a layer of water in glass, and a dense cloud of steam blown from a kettle allow the nose-closing rays of a dull-red source to act, and convert an incandescent source into a nose-closer. An incandescent lamp so screened closes the author's left nostril many feet away where no sensation of warmth is felt. Cellophane lessens the lamp's energy by about ½ and horny layers of the skin by ⅔.

Nose-closing results, in the case of the author, from suitable irradiation of any part of the skin with the exception of the palms of the hand and soles of the feet. These parts sweat on emotional excitement in order that the grip may be good. They do not sweat to cool the body as the rest of the skin does. When the nose is closed by irradiation of one part of the skin it can be opened at once by fanning and cooling that part, and by more intense cooling of some other part.

The nose-closing reflex is not provoked from skin which is wet.

Nose-closing is prevented for about two hours after inhalation of a spray of a solution of adrenalin, which produces constriction of the respiratory membrane.

Taking the time of exposure required to close the nose and the distance from the source, a dull-red electric heating unit, Dr. H. J. Taylor, the author's physicist colleague, found the effect to be as $\sqrt{i} \times t$ where $i =$ intensity, and $t =$ time. Using different sized square holes in cardboard screens, and applying one or other of these screens to the skin of the body, with the source 2 yds. from the hole he found the effect to be as $\sqrt{a} \times t$ where $a =$ the area of the skin exposed and $t =$ the time.

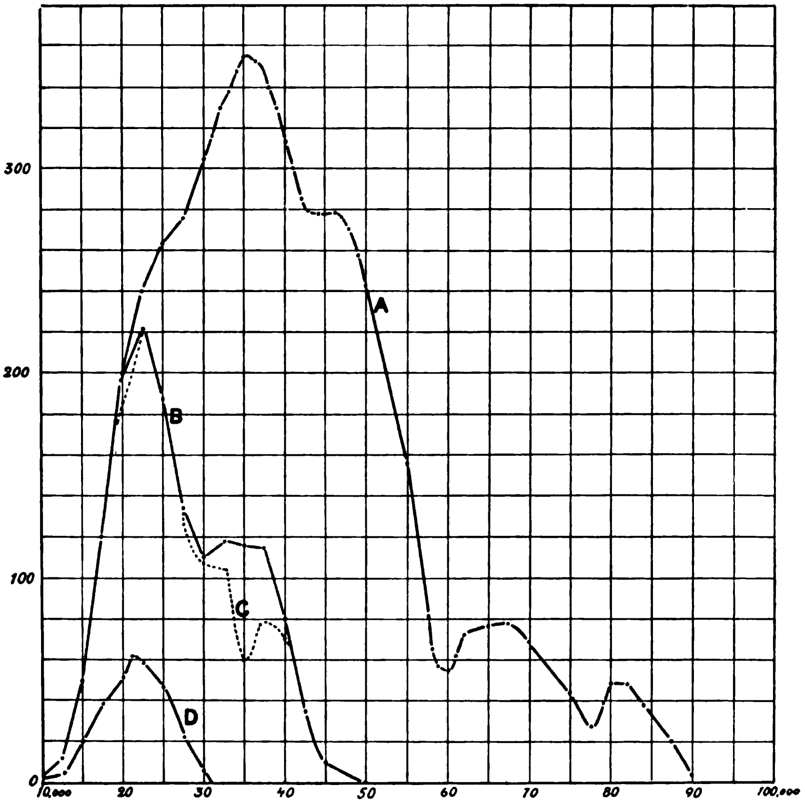
It has been suggested by Dufton and Bedford that the nose-closing effects produced in the author are due to the play of imagination. Perhaps these critics will explain how the imagination was able to respond while Dr. Taylor secured readings which allowed him to calculate these formulæ, the author knowing nothing of the distances, times, or size of areas.

While a dense cloud of steam converts an incandescent lamp into a nose-closer, the invisible vapour rising from a trough of water protects the author from nose-closing rays when this is set in front of a dull-red or black surface. The water trough must be between the source and the subject; it is ineffectual when put to one side. In this screening effect is to be found an explanation of the custom of putting a trough of water in front of stoves. An apparatus is now on the market which is designed to circulate the air of a room through a wet screen by means of a fan. This acts locally and has the same effect as the trough. The conditioning of air similarly influences the action of radiant energy on the skin.

Noteworthy is the fact that the nose-closing effect of a dull-red or black source is set aside by rays from a bright source, such as an incandescent lamp. The counteraction is provoked by irradiation of the same or some other part of the skin. A balance can be found between the two sources so that varying the distance from one or other provokes nose-closing or nose-opening. Thermopile readings showed that the energy of the nose-opening rays to be effective need be only some one-fiftieth of that of the nose-closing rays.

Dr. H. J. Taylor has determined the emission of various sources of heat and the absorption produced by screens used in this research.

Figs. 2, 3, 4 and 5 show the results of his measurements. They were taken with a Hilger rock-salt spectroscope and a thermopile. The inference was drawn in the author's previous paper from these observations, that the nose-opening rays lie in the region about 30,000 A.U. A glass screen weakens the rays in this region but cuts out the longer infra-red rays. It affords considerable protection against the nose-closing effect of the electric fire. On the other hand, a glass screen converts the sun and a long-flame arc into nose-closers. A layer of water in glass cuts out most of the energy of an electric fire, but the rays which pass in the short infra-red region act as nose-closers. It is difficult to explain these effects on physical grounds.



A Emission curve of electric fire.

B With glass screen.

C With film of water on glass screen.

D With water flowing over glass screen.

FIG. 2.

The author is not alone in his sensitivity to certain infra-red rays. His colleague, Dr. Rattray, is even more sensitive to nose-closing rays but less sensitive to nose-opening ones. As in the author's case a balance can be struck between the nose-opening and nose-closing rays. A single step taken nearer one or the other source disturbs the balance. In such experiments the incandescent lamp must be used without a reflector for such gives off nose-closing rays.

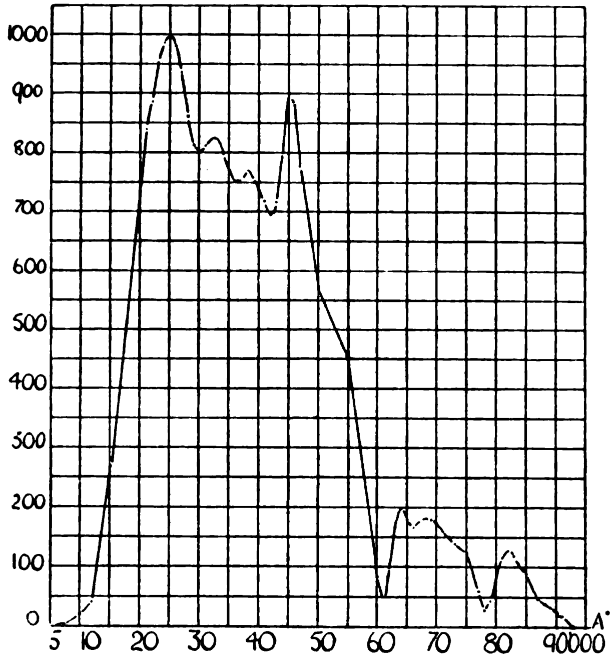


FIG. 3.

Infra-red spectrum of one of the Radiation, Ltd., " Beam " radiants, the mantle of which has been impregnated in order to improve the emission of short infra-red rays, a " nose-opener."

One of the porters at the London Clinic and Institute of Physical Medicine has the airway of one side of his nose restricted as the author has, but not quite so much. Breathing through this nostril is made difficult for him on exposure to a dull-red electric heater and easier again when an incandescent lamp is switched on. Fanning widens the airway of both these subjects, and in both, the airway is opened by pulling the wing of the nostril outwards.

A clerk in the Clinic's office is also similarly sensitive.

Investigation of a large number of nurses and patients at the Clinic, with help of the screw nose-clip, showed that many feel that breathing is less free, when exposed to the electric heater, and made free by fanning, and by switching on an incandescent lamp. Thus 38 out of 42 were made easier by the fan; 19 out of 33 by the incandescent light; 8 out of 12 by the water trough put in front of the electric fire.

Many patients who come to the Inhalation Ward say they like open windows and are made uncomfortable by shut up warm rooms. Most normal wide-nosed people can be made sensitive to nose-closing and opening rays by the use of a screw nose-clip, adjusted so as to restrict the airway up to the time when breathing is only just adequate. Several distinguished research workers were among the subjects who were thus proved sensitive to nose-closing and opening rays. There are some quite insensitive to these rays. Two medical men have told me that patients whose faces are irradiated with a dark electric heater complain of stuffiness; while when irradiated with an incandescent lamp they feel comfortable.

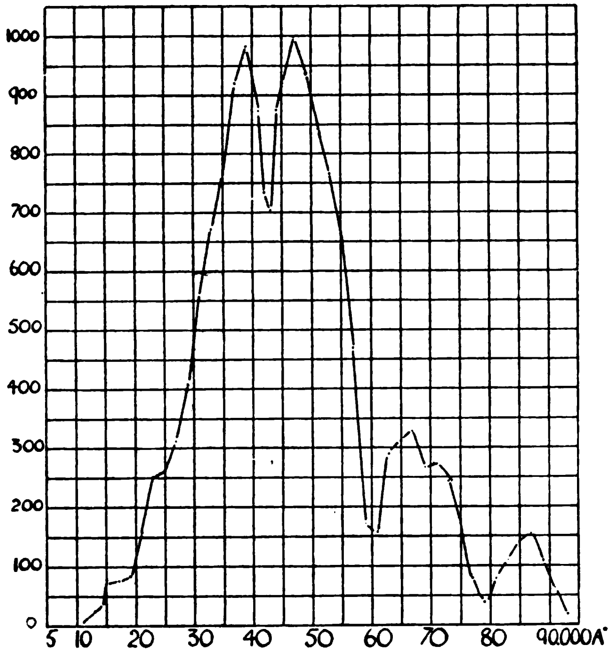


FIG. 4.

The radiation emitted by a source of dark heat at about 400° C., a "nose-closer."

It has been suggested by Dufton and Bedford that the nose-closing effect is merely due to heat. Against this is the fact that the nose remains open when the face, while exposed to the long flamed arc (2 yds. away), is brought so close to a dull-red electric fire that the heat becomes unbearable. Moreover in the author's experiments he uses only 1/60 of the energy used by Dufton and Bedford.

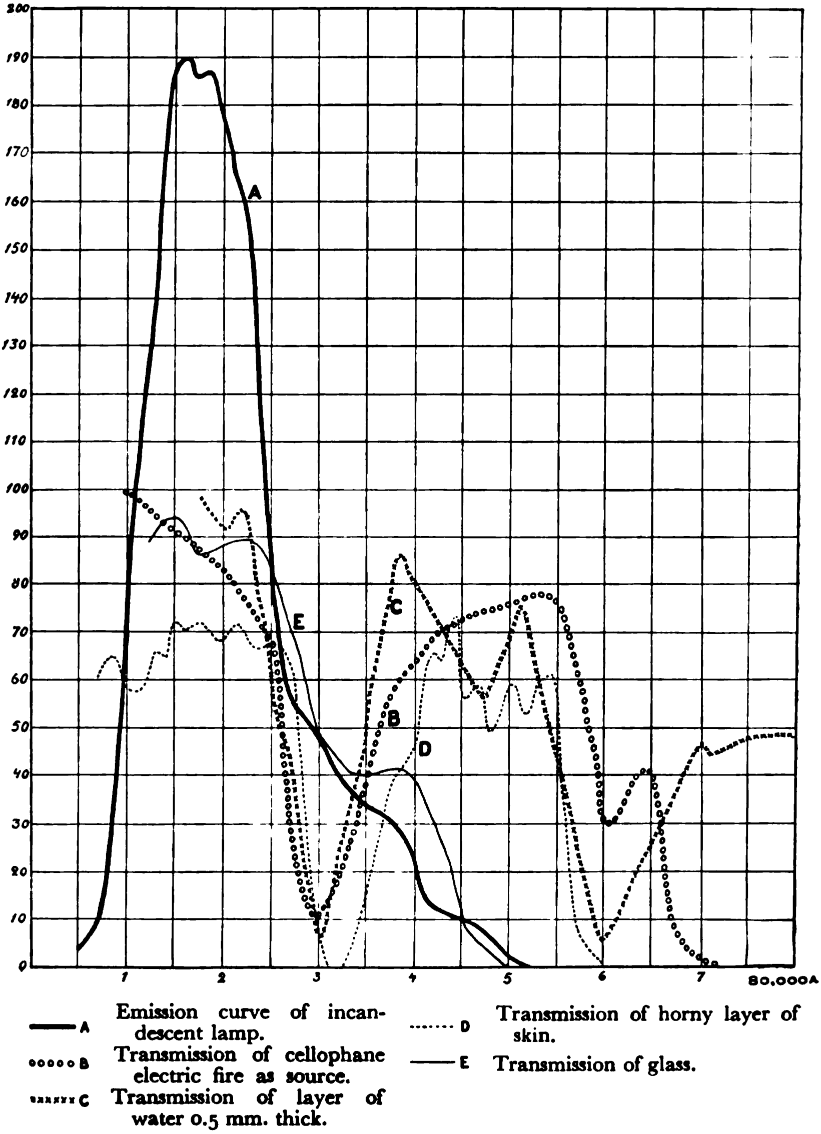


FIG. 5.

Miss Murray of the Physiological Department, Bedford College, has irradiated the skin of the upper arm in many subjects with a bowl-shaped electric heater while recording the breathing by means of a stethograph. One nostril of the subject was closed and the mouth gagged. About 60 subjects, mostly females, were studied and in some 25 of these some signs of altered respiration was noted concomitant with the irradiation. In a few cases the restriction of breathing resembled that found in the author. Fanning gave relief.

Miss Murray did not particularly study the counter-effects of rays from an incandescent lamp, but another expert research worker, Dr. W. Thomson, has confirmed the nose-opening action of these rays in many sailors observed by him in H.M.S. *Excellent.* Dr. Thomson used the nose-clip and in other respects followed the author's methods. A bowl-shaped electric heater was used as the source of nose-closing rays. Fanning gave relief in all cases except in the case of a man with a catarrhal condition of the nose.

Recently a paper has been published in the *Journal of Hygiene* by Dufton and Bedford in which it is claimed that the author's experiments are refuted. These authors did not use the author's methods but put a tube in one nostril and connected this with an aneroid recording tambour, the other nostril being reserved for breathing, and so measured the negative pressure produced by inspiration. Now it is easy to show with the help of a water manometer that the airway of one nostril is normally five or six times larger than is required for the passage of the air during quiet breathing. Their method then is most insensitive, and can only be expected to give a result in a subject with a restricted nostril.

Further, these authors compared the effect of two electric-bar fires, one bright and the other dull, but they left the reflectors on, and placed the fires so that the long infra-red rays from the reflectors would have full play on the subject's face. Both fires, then, would act as nose-closer to one like the author. Elaborate precautions were taken to move the fires silently to and fro, and 30 blind men from St. Dunstan's were used as subjects so that there might be no play of the imagination.

Dufton and Bedford thus carried out an elaborate and expensive set of experiments which were so designed as to yield a negative result.

The following conclusions are made :—

1. The quality of radiation is important in the production of comfort and for health.
2. The short infra-red rays which penetrate the skin and excite flushing and transpiration are more comfortable than the longer non-penetrating rays which heat the surface.
3. Owing to the character of their radiation bright sources of heat are more comfortable than dull-red or dark sources.

4. When dull-red or dark sources of heat are used their stuffy action should be counteracted by enough ventilation with cool air to produce a feeling of freshness.
5. Loss of body heat by radiation to cold walls or to the sky through windows, counteracts the stuffy action of such sources, but in a less comfortable way.
6. Dull-red and dark sources congest the respiratory membrane so as to close a restricted nasal airway and cause stuffy feelings.
7. The nose-closing effect produced by such sources is counteracted by cooling the same part of the skin as that irradiated, or some other part.
8. In many subjects the nose-closing effect is counteracted by simultaneous irradiation of the same, or some other part of the skin with rays from an incandescent or arc lamp.
9. In some people the sensitivity of the skin to the quality of infra-red radiation is very great.
10. The difference in reaction to such radiation probably explains why some people like open windows and cannot bear to be shut up in heated rooms, while others enjoy such rooms and regard the first as open-air fiends.

DISCUSSION.

Dr. W. A. R. Thomson, at Sir Leonard Hill's request, showed a table in the form of a lantern slide giving the results of some experiments which bore out the author's arguments. Dr. Thomson said that he had summarised in the table the results found in 54 cases investigated with regard to their reactions to electric radiators and to incandescent light. In each case the nose was closed by means of a nose-clip to such a degree that quiet respiration could be maintained at rest for an indefinite period without any distress. The distances at the top of the columns in the table referred to the distance of the patient from the radiator.

INFRA-RED RAYS AND RESPIRATION.

	Two Feet	Five Feet	Ten Feet
Total Cases	54	54	22
No Difficulty in Breathing	4/54 = 7.5%	8/54 = 15%	7/22 = 32%
Eased by Fanning ..	46/50 = 92%	43/46 = 93%	13/15 = 87%
Eased by Glass ..	22/33 = 67%	19/27 = 70%	10/15 = 67%
Eased by One Light	13/50 = 26%	17/46 = 37%	6/15 = 40%
Eased by Two Lights	6/28 = 21%	8/21 = 38%	6/12 = 50%
Eased by Lights ..	19/50 = 38%	20/46 = 43%	8/15 = 53%

The table was self-explanatory, and two noteworthy points which should be noted were (*a*) that of the 54 cases there were only 4 who did not experience difficulty in breathing when placed in front of the radiator, and (*b*) that the farther away the case was from the source of heat the more pronounced was the "nose-opening" effect of the incandescent source of heat. Taking all cases and all distances from the radiator, it was found that of the cases who found difficulty in breathing, 92 per cent. were eased by fanning of the face, 80 per cent. were eased by means of a sheet of glass placed between the face and the radiator, and 52 per cent. were eased by an incandescent source of heat.

There was one further point of interest with regard to what had been said regarding the beneficial effect of open-air treatment of disease. Until recently the speaker had been engaged upon research into the ætiology of acute rheumatism, and part of his work had been carried out in a convalescent hospital laid out on the pavilion plan. It had been found that the incidence of hæmolytic streptococci happened to be much higher in the patients in this hospital than in those in hospitals where open-air therapy was not possible, and yet the incidence of illness due to this organism was much less than in the other hospitals. The only explanation that seemed to explain these facts was that in the convalescent hospital the patients' general resistance was so greatly increased by means of treatment in the open air that, although they harboured these organisms in their throats, yet they were less susceptible to any of the illnesses which this organism might cause.

Mr. W. E. Fretwell, Senior Vice-President (who at this point occupied the chair of the meeting), said that he had to express to Sir Leonard Hill the apologies of the President, who had to leave to attend another meeting that was fixed many days ago. He thanked Sir Leonard Hill for his very interesting and scientific paper; everyone was aware of Sir Leonard's eminence in this physiological subject. It was not the first time that Sir Leonard had lectured to the Institution, but all would agree that this was probably the most interesting of all his papers. Not only had he prepared this paper at considerable pains, but he had delivered it with an impressive enthusiasm. He then referred to a number of distinguished visitors present, and expressed the hope that they would take part in the discussion.

Mr. E. R. Dolby said that he had read an advance copy of the paper with much interest, but with some disappointment that so much space was devoted to "nose-closing effects" which he himself did not feel competent to discuss. He proposed to confine his remarks to the term "cooling power" as used by the eminent author in connection with the results obtained with his kata-thermometer. He ventured to suggest to him that he should help them to correlate such results with the well-established rules for the design of low-pressure hot-water heating installations. In order to make his meaning clear he hoped he might be allowed to cite two purely imaginary incidents. The first concerned an architect who had designed an important new building. Following his usual practice, he sent out a set of copies of the drawings with a copy of what he called his general conditions to each of three or four firms of heating contractors, and invited them to submit competitive schemes for heating, with estimates of cost. He was very desirous of being up-to-date, and he had read the results of recent researches by Sir Leonard Hill and others, and had been much impressed by the magic phrases " radiant heat " and " comfort effect." Therefore, he added to his general conditions a new paragraph which read : " Testing :—On completion of the work the contractor shall provide dry-bulb and wet-bulb kata-thermometers and a hot wire anemometer and shall test in the presence of the architect and prove that in each room the cooling power is not below seven." The contractors immediately " spotted " this new clause and decided to ask the architect precisely what it meant. He told their representatives that he did not propose to teach them their business, that they must read the papers, the titles of which he cited. The first contractor decided to allow £10, the second £20, and so on, the last decided to ignore the clause entirely, and take the risk ; he submitted the lowest tender and got the work. On completion of the contract, the architect said to the contractor, " When will you test for cooling power ? " whereupon the manager said, " We had to sign a sub-contract with the builder and nothing is said there about testing, so we have not provided for it, but the building is beautifully warm everywhere."

The second incident concerned a consulting engineer retained by a county council to design a heating installation for a new school. He attended a meeting of the special committee when the medical officer of health was present. The latter said, " Now, we want this new school to be a model. You must please allow in each room for a cooling power of seven and complete comfort effect, and I shall attend your tests." The consulting engineer pondered these remarks, and decided to prepare the design on his usual lines, to add a provision of £50 for testing and obtain competitive tenders at once.

The speaker maintained that such incidents did not represent situations which were at all exaggerated, and that it was high time that some agreement should be reached between physicists, psychologists, and medical men on the one hand, and the large body of persons responsible for the design and construction of heating installations on the other, and the author might help them to attain this desirable result.

Mr. A. F. Dufton said that in his preamble the author made the unqualified assertion that Vernon found that a room heated by ceiling panels to 55° F. gave the same feeling of comfort as one heated to 65° F. by convection. This could hardly be allowed to pass and he was glad to see that Dr. Vernon was present to tell them more about it.

The author had also stated that Dr. Bedford, and the present speaker, had suggested that the nose-closing effects produced in him (Sir Leonard) were due to the play of imagination. He could not find that they were responsible for this, although they had certainly remarked that suggestion might possibly be a contributory factor in counteracting the effects.

With regard to the statement that Dr. Taylor secured readings which allowed him to calculate the formulæ $\sqrt{i} \times t$ and $\sqrt{a} \times t$, he wished to observe that it might be more convincing if the experimental conditions were described and if the actual observations were tabulated, preferably for more than one subject. So far as he was aware, no account of these experiments had been published, and although the author had referred to them on more than one occasion, the speaker had not considered them as a serious contribution to knowledge.

He thought it was to be regretted that the author did not consult his physicist colleague before indulging in damaging statements about the long infra-red rays from the reflector of an electric fire. The polished metallic surface of a reflector, of course, emitted scarcely any radiant heat. The author was content, moreoever, to forget that his so eminently suitable clinical gas lamp was provided with a similar reflector. His stricture, therefore, that " Dufton and Bedford thus carried out an elaborate and expensive set of experiments which were so designed as to yield a negative result," was unwarranted.

The author stated that he cut a hole in a screen of cardboard just big enough to push the nose through for breathing the hot air when close up to the electric fire and that this had no nose-closing effect. It would be interesting to know how he reconciled this with his statement that the nose might be shut by rays from an electric fire a yard away acting on an area of skin 1 in. square.

There was one point which the author brought out in his paper in the Quarterly Journal of Experimental Physiology which he had not mentioned that day: he found that covering the face with the bedclothes had a nose-shutting influence, which might be counteracted by thrusting out a naked leg.

Of all the evidence which had been adduced against the author's theory, the palm must be given, the speaker thought, to the surprising facts which he had described that day: nose-closing was produced reflexly from the skin on a cold frosty winter afternoon when the setting sun, which produced no sensible feeling of warmth, was screened by ice ! Where, one was tempted to ask, did the infra-red rays go in the winter-time ?

He wished to conclude these remarks by saying that the previous week he had received a letter from Professor Winslow, of Yale University School of Medicine, telling him that he had just finished a study somewhat similar to that of Dr. Bedford and himself and that his conclusions were essentially the same as theirs.

Dr. T. Bedford said that Sir Leonard Hill had advanced certain criticisms against the paper by Mr. Dufton and himself. One of these was that both the electric-bar fires used by them were fitted with reflectors, and that infra-red radiation from the reflector would convert such a fire into a nose-closer. On account of this, it was said, their experiments were so designed as to yield a negative result.

It was easy to show by actual experiment that this criticism would not hold. He had removed the reflector from the brighter of their electric-bar fires, and by short-circuiting a portion of the bar he increased its brightness considerably. He showed on the screen a lantern slide illustrating the tracing of the subject's respiratory pressure which brought it out quite clearly that, even without the help of a reflector, such a bright source of heat was a potent nose-closer. This experiment proved that the use of reflectors did not make worthless the investigation by himself and his colleague as Sir Leonard Hill would suggest.

The author's criticism was levelled at their use of electric fires. He made no mention of the fact that two of his nose-opening sources, namely, the sun and the clinical gas-lamp, were found by them to be nose-closers. It might also be remarked that the clinical gas-lamp acted as a nose-closing source even when the reflector was removed.

A further criticism of Sir Leonard's was that the method of recording used by them was not sufficiently sensitive, yet in a paper published last year Sir Leonard had mentioned that he had adopted the same method, and gave a specimen record. He said now, that the Dufton-Bedford method could only be expected to give a result in a subject with a restricted nostril. That criticism seemed rather weak, for, as could be seen from the diagrams published in their paper, and in that which he had just shown on the screen, most pronounced nose-closing effects were recorded in subjects whose inspiratory pressure when breathing quietly was only about 1 cm. of water. Yet under similar quiet conditions a subject with a deflected septum had an inspiratory pressure of anything from 5 to 8 cm. of water. The aneroid which they had used was in fact a very sensitive instrument.

The author had mentioned that the warmth of the sun with a cool breeze felt most genial, and on the cliff edge, exposed to loss by radiation to the cold sea, and to a sea breeze, one also felt braced.

On stepping into a greenhouse, however, the sensations changed at once, and in Sir Leonard's own case the nostril became closed. This effect he ascribed to infra-red radiation. In an earlier publication,* however, Sir Leonard had referred to a similar experience in a greenhouse on the East Coast, and had said : " This, with the windows and door open, was agreeable when the sun was clouded, but produced headache, stuffiness and unpleasant heat of the head when the sun was out, in spite of the breeze blowing in. . . . The left side of the nose became blocked owing to swelling of the mucous membrane. . . . The radiant energy of the sun falling on the head was the chief offender, as was evidenced by the relief felt on screening it off or given by a passing cloud."

Dr. H. M. Vernon said that he had not intended to intervene at all in that discussion, but he must correct one mistake that Sir Leonard Hill had made in ascribing to him the view that a room heated by ceiling panels to 55° F. gave the same feeling of warmth as one heated to 65° F. by convection. He had said nothing of the sort. The difference was not a matter of 10° F., but from 1 to 2° F. He found that out by several different methods, and the effect had always been consistent. It was true that at the Embassy at Washington the difference was as much as 6° F., but there they had two or three times as much heating surface of panels as in this country.

The author had stated that air moving at about 110 ft. a minute might just cause a sensation of draught. The speaker and his colleagues had made many tests on this point, and they had found that one could appreciate an air current at about 30 ft. a minute if at all cool and at about 50 or 60 ft. a minute if warm.

Dr. G. P. Crowden desired to ask Sir Leonard Hill to clear up the point about the percentage of people sensitive to this reaction. In the early part of his paper he had mentioned that 50 per cent. were sensitive and experienced discomfort, but did that 50 per cent. relate to people wearing the nose-clip or was it 50 per cent. of the ordinary population ? If it was 50 per cent. of people when wearing the nose-clip, it was of little significance, because to wear a nose-clip was not a customary habit, but if it applied to 50 per cent. of the population in everyday life it was, of course, a matter of considerable importance.

There was one point on which he found himself in absolute agreement with Sir Leonard Hill, namely, that the tendency to divorce heating from ventilation was a very serious matter.

In Sir Leonard's demonstration that afternoon he had been a little surprised to see the extraordinary rapidity with which the action of the rays took effect in producing nose-closing. He could understand a muscle working very quickly in response to a stimulus, and he could understand the contraction of the blood vessels in the nose occurring rapidly, but when one got mechanical blockage of the airway in the nose due to the flushing of an area with blood it must take an appreciable period of time, longer, he would have thought, than the demonstration had suggested.

---

* Medical Research Council, Special Report, 32, p. 14.

The effect of heat in producing a reflex dilatation of the blood vessels was fairly well established not only by these experiments but by others, and also, indeed, by observation of common experience. It was certainly very interesting that Sir Leonard should have drawn attention to the rapid effect of radiant heat, whether from one source or another in producing this reflex, and the experiments of Dufton and Bedford, which were conducted with extreme care, had shown that when a sudden relative warming of the surface of the skin occurred, then this reflex action was elicited and demonstrable in the nose of sensitive subjects.

There was a point of discrepancy which occurred to him in the illustration Sir Leonard had used from the House of Commons. If, as he stated, the air was impelled through slits in the floor, so that there was a cooling effect on the feet, how was it that this, according to his later argument, did not render the conditions there more comfortable by producing nose-opening or preventing nose-closing? One did want it cleared up as to whether or not in actual practice in the ordinary home radiation from dull red and dark sources of heat really amounted to so serious a matter as some organs of the Press seemed to think.

Dr. Oscar Faber, in supporting the vote of thanks to Sir Leonard Hill, said that there were a few questions which occurred to him. One thing he could not understand was the shielding by water vapour which was produced by holding a carafe of water with the neck practically closed and a tumbler containing some water at some little distance below the direct line between Sir Leonard's nose and the source of heat. He could not really conceive that any appreciable quantity of water vapour could be escaping from those two vessels containing water, and he was surprised that so rapid a reaction appeared to follow.

Many of those present that afternoon were actively interested in applying heating and ventilation to actual structures, and he was not quite clear what lesson they as practical people were to learn from the paper that they had had before them. Its value would be greatly increased if in his reply, whether verbal or written, Sir Leonard would indicate a few of the lessons which might help them in their work. For example, he was not quite clear whether the conclusion was in favour of, or against, several well-known forms of heating and ventilation, and if Sir Leonard could tell them, for example, whether he thought that panel heating was good or bad, and the same with hot-water heating, steam heating, and so on, it would be of enormous interest. He had gathered that any infra-red source of heat was bad, and therefore he concluded that the open fire, which did radiate infra-red heat when it was efficient, was also bad, but he had never personally found anybody who suffered any feeling of discomfort from the radiation of an open fire. Was that a correct observation or otherwise? If it was correct, he did not understand how it was consistent with the observations quoted and also indeed with the fact that the other effects of infra-red radiation were eliminated by passing a sheet of glass in between the person and the source. It would appear, if they could be eliminated in that way, that if any radiator were supplied with a sheet of glass in front of it the whole difficulty would disappear. If that was true he was surprised that the manufacturers had not discovered it before.

Sir Leonard Hill, in reply, said that Mr. Dufton had asked about the nose-closing action when he made a hole in a cardboard screen and went close up to the fire. He (the speaker) should have said that he was careful to make that hole of just sufficient size to come against the opening of the nostrils. With regard to the fact that nose-closing was produced reflexly when the sun was screened by ice, certain wave-lengths came through, but the identification of the nose-closing rays had yet to be made. That the effect occurred there was no doubt, just as it occurred when a screen of glass and water was used. Mr. Dufton had mentioned Professor Winslow. He also had been in correspondence with Professor Winslow, who used the method which was employed by Dufton and Bedford, which was not sensitive enough. He had posted to Professor Winslow a screw nose-clip and asked him to try that method. He thought that those who contradicted him should at least try the nose-clip method, and see if they failed to get the results which had been confirmed in so striking and independent a manner by Dr. Thomson.

With regard to Dr. Bedford's recent experiment with a bright fire, if the source were placed too close this would obstruct the nose of a very sensitive subject such as his colleague, Dr. Rattray. Both Dr. Bedford and Mr. Dufton had referred to the fact that the sun acted as a nose-closer on a subject studied by them. He would want to know whether the sun experiment was done out of doors, or in a room where the sun came through glass.

Dr. Bedford mentioned the fact that he (Sir Leonard) had taken some records by the same method that he and his colleagues had used. So he had; if one had a restricted nose such as he had, one could use that method, because the nose was a very sensitive indicator. He had slides, with which he had not troubled the meeting, showing all the effects he had described, recorded in tracings upon a drum. These were taken with the tube up one nostril. Such effects would not be forthcoming in the case of a normal wide-nosed person, or in one with deflected septum who was not sufficiently restricted.

In the greenhouse experiment mentioned in the paper, part of the effect was due to the sun acting through the glass and striking his skin. The absence of ultra-violet rays had nothing to do with it, because the effect was noted in a greenhouse built of vita glass.

In regard to Dr. Vernon he would gladly correct the paper by accepting the fact that from 1 to 2° was all the difference found. This had nothing to do with the main argument of the paper.

Dr. Crowden had asked about the House of Commons. The term " cold feet " was rather an exaggeration. The cooling power as shown by the " kata " was 50 to 100 per cent. greater at foot level than at head level. The head was in stagnant warm air. Under those conditions people like himself were made uncomfortable and their noses were shut up. If air were introduced at gallery level and all the floor inlets were closed the conditions were made quite comfortable. In 1913, a vote was passed in Parliament to carry that out on a large experimental scale, but the war came, and it had never been done to this day.

Dr. Crowden had mentioned the rapidity with which the reflex effects were shown during the demonstration. They certainly looked rapid, but they were not nearly so rapid as might be thought. He had measured the time it took, using a weak source some little distance away, and it required something like five to six seconds for an effect to come off. That was an effect which might well be produced by a reflex on the nasal mucous membrane.

He had been asked whether this whole question was of any serious importance. Well, it was to people who were sensitive, like himself and Dr. Rattray. The latter was made very uncomfortable by working in a room heated by a large radiator coil ; he got many catarrhal colds. When he was given a stove of the Ferranti type which had got a bar with six amperes going through it, and that was put on the floor so as to warm his feet, he was much more comfortable. There were many people who were so affected. He had letters from several correspondents who said they could not stand an electric fire.

Among the small staff of the London Clinic and Institute of Physical Medicine he had found four persons, so that the incidence could not be very low. A number of members of the House of Commons made complaints about uncomfortable ventilation, whereas, on the other hand, some members declared the ventilation to be quite efficient. It was the same with railway trains ; some people liked a shut-up compartment, and others could not bear it. If it were admitted that radiation was important, the thing to do was to compensate for its ill-balanced effects. Bright sources, such as the open fire, were comfortable but the hot surroundings of such a fire were nose-closing and uncomfortable when the bright part was screened off. The fire gave off water vapour and it was noteworthy that people had been putting water-troughs in front of stoves for a long time, and that greater comfort had been experienced thereby. The thing to aim at, where dull red or dark sources of heat were used, was to ventilate freely with fresh air. By such means greater comfort was obtained while health would be improved and infection stopped to a very large extent. The members of the Institution he was addressing had the comfort and health of the people in this respect very largely in their hands. They could influence the conditions of workshops and houses to an enormous extent, and he trusted they would endeavour to think out the best arrangements from the point of view of health and comfort.

On the proposition of *Mr. W. W. Nobbs* a vote of thanks was accorded by acclamation to Sir Leonard Hill for his interesting and instructive paper, and the meeting terminated.

PAST-PRESIDENTS' LUNCHEON

THE tenth annual meeting of the Past-Presidents of the Institution of Heating and Ventilating Engineers was held on Tuesday, February 13th, at the Hotel Russell, London, W.C.1, when seventeen Past-Presidents sat down to luncheon with Mr. James Elliott, the President, as their guest. Sir Louis Pearson, C.B.E., presided.

Apologies were received from Past-Presidents W. Nelson Haden, A. Basil Simpson, P. M. B. Grenville and A. A. Jones who were unavoidably absent.

Mr. Frank Biggin, Convener, called attention to the fact that the Institution had now twenty-two Past-Presidents, one was out of the industry and had resigned, and the fact that seventeen attended showed that they were not indifferent to the affairs of the Institution.

Sir Louis Pearson called upon Mr. Nelson Russell, who was the Past-President in 1902, to propose the toast cf the Institution. He spoke of the importance of the younger members whom he said should take an active part in the Institution.

Mr. James Elliott, President, responded and referred to the expansion of the Institution and the inauguration of branches in Liverpool and Birmingham, and of further branches in the future.

Mr. Walter W. Nobbs referred to the activities of the Institution in various directions, and particularly of the Research Control House being proceeded with at once. He also said that the Council had under consideration the founding of a Benevolent Fund in connection with the Institution. The Mechanical Engineers have such a fund from which they can render pecuniary assistance.

Mr. E. Herring said that he had been looking forward to the meeting of Past-Presidents for some time, and expressed his appreciation of the concern and sympathy in his long illness last year. (It was a pleasure to all to see him looking so well again.) Incidentally, he stated that he had been 50 years with his firm.

Mr. J. L. Musgrave and Mr. Roger Preston also spoke.

Mr. J. W. Cooling proposed the toast of the Chairman.

Sir Louis Pearson responded in a reminiscent mood and spoke of the difficulties which had to be dealt with in the early days of the Institution.

This reminiscent mood spread to the other Past-Presidents, and it was interesting to hear that several of them had been connected with the heating industry over 50 years. Mr. Naylor spoke of 58 years, Mr. Biggin had been with his firm over 51 years, Mr. Walter Yates 51 years, Mr. Fox 48 years and Mr. Herring 51 years.

It is interesting to find men who can look back with so much pleasure, and apparently with as much pleasure and certainly with more certainty than other younger men can look into the future.

Building Research Station, Garston, Nr. Watford, Herts.

ECONOMY IN FACTORY HEATING

By A. F. DUFTON, M.A., D.I.C.

It is not uncommon practice to heat an industrial building by means of steam pipes situated above head level. Where the roof of the building affords little thermal insulation, as in many factories, such a system is likely to be particularly inefficient : the air heated by the pipes rises directly to the cold roof, cold down-draughts are sometimes experienced and the roof has to become heated before the building is warm. The layout of a heating system of this type has, however, certain attractions and, in view of these, some consideration has been given to the possibility of making the system more efficient.

It would appear that a simple method of reducing the waste of heat and of directing the heat downwards would be to invert over the steam pipe a shallow wooden trough. This would hold the air warmed by the pipe, the lower surface of the wood would become heated and would radiate heat downwards. In order to investigate the possibilities of such an arrangement, comparative tests have been carried out in two, similar, small rooms roofed with asbestos-cement sheets and a quantitative measure of the effect has been obtained.

For convenience, electrical heating was used in lieu of steam. A 2 in. tubular electric heater was installed at a height of 7 ft. 9 in. in each room and one heater was fitted with an inverted wooden trough, 18 in. wide and 3 in. deep, made of 1 in. deal (Fig. 1). The input to this heater was reduced so that the surface temperature of the tube was the same as that of the other heater (about 180° F.),

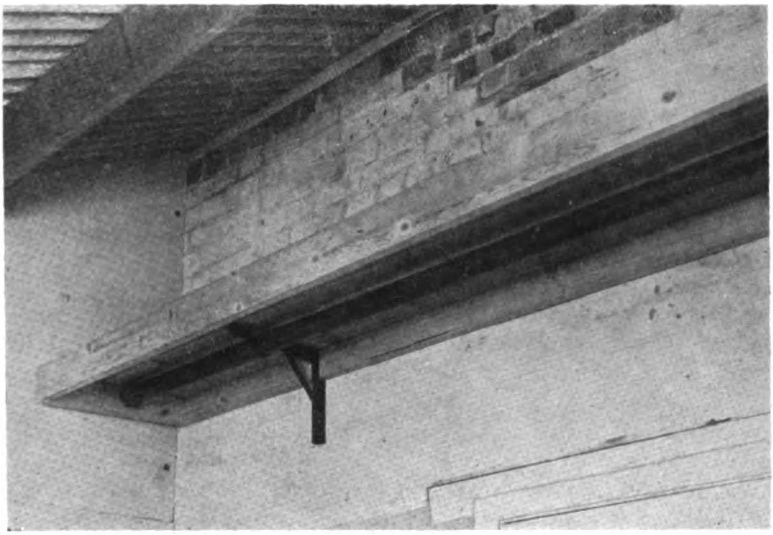


FIG. 1.

the temperatures being compared by means of thermocouples attached to the tubes. A eupatheoscope was installed in each room and air temperatures and equivalent temperatures were recorded.

Measurements were made over a period of 48 hours. The trough was then removed and installed over the other tube, the electrical inputs were readjusted to give equal surface temperatures and the experiment was continued for a further 48 hours.

This duplication was carried out in order to eliminate any possible effects which might arise from small differences between the rooms, the eupatheoscopes or the meters for measuring the electrical supply. The records obtained, in fact, showed that such differences were negligible.

The experiments, which were carried out by the author's colleague, Mr. W. G. Marley, showed that, while the air temperature and the equivalent temperature in the room in which the trough was installed were each half a degree Fahrenheit higher than those in the other room, the amount of heat supplied was only 32.1 units of electricity instead of 44.5 units.

The installation of the wooden trough or canopy over the heating pipe resulted in an economy of 30 per cent. in the amount of heat required.

Although this experiment was carried out in small rooms, there can be no doubt about the principles involved or that substantial economies can be effected in larger buildings.

ABSTRACTS

Small-Ion Content of Air 533·3

Daily observations of the small-ion content of outdoor and indoor air from May 1930 to May 1933, disclose definite diurnal and seasonal variations depending largely upon local and general meteorological conditions.

The most important climatic factors affecting the small-ion content of outdoor air appear to be the inter-diurnal changes of temperature and humidity. A drop in the inter-diurnal temperature and humidity is as a rule preceded or accompanied with a sharp rise in the ion content of air, and vice versa, provided that the drop or rise in temperature and humidity does not continue more than two days.

Cloudiness, high humidities, and light or moderate precipitation of any kind have a detrimental effect on the small-ion content of outdoor air. Heavy precipitation results in a considerable increase in the number of small negative ions, and when the precipitation is accompanied with thunder and lightning both positive and negative ions attain very high values.

In the locality of Boston, high concentrations of small ions are as a rule associated with winds from the W. and N.W., which usually bring sharp drops in the inter-diurnal temperature and humidity and clear weather. The actual temperature and barometric pressure are not very important so long as the relative humidity is well under 75 per cent.

Low concentrations of small ions are generally associated with stormy winds from the E. and N.E., which are often preceded with a rise of temperature and humidity finally culminating in rain or snow. The minima occur in damp or moist weather when the temperature is under 50° F.

In winter, the concentration of small ions in indoor air is considerably lower than that in outdoor air. In summer the reverse seems to hold true. Adverse weather of short duration does not conspicuously affect the indoor concentration in spite of powerful effects on the outdoor ions. Persistent bad weather tends to equalise the outdoor and indoor ion numbers.

In the light of the present study it would seem that the small ion content of the atmosphere is an important meteorological factor which deserves wider recognition and more study than heretofore afforded to it. (C. P. Yaglou and L. Claribel Benjamin. *American Society of Heating and Ventilating Engineers*, February 1934.)

HEATING AND VENTILATING INDEX

Automatic Control. 697·97

Automatic Controls. 4 pp., 3 illus. Dealing with fan setting control, fan operation, stack limit control in connection with warm air furnace : *American Artisan*, December 1933.

Refrigeration. 697.96, 621.565

Air Conditioning for Heating Contractors. John Everetts, Jr. 1¾ pp., 1 illus. Dealing with the theory of mechanical refrigeration and application of the heat pump or reverse cycle : *Bull. of Heating, Piping and Air Conditioning Contractors Nat. Assoc.*, December 1933.

Safety Valves. 621.133.9

Steam Pressure Control. Donald MacNicoll. ¾ pp. Review of progress in theory and practice of steam valves and valve gear ; *The Glasgow Herald Trade Review*, December 29th, 1933.

Steam Flow. 621.185

Control and Measurement of Steam Flow. C. S. Darling. 1¾ pp., 2 illus. Dealing with thin plate orifice and pulsating flow : *The Steam Engineer*, January 1934.

Heat Losses. 536.2

Heat Losses. Leslie Rayner. 3½ pp., 3 illus. Dealing with calculation of heat loss coefficients, tables of coefficients, room temperatures and air changes, aspect and temperature in unheated rooms : *The Plumber*, January 1st, 1934.

Gas Heating. 697.6

Le Reglage Thermostatique des Installations de Chauffage Central au Gaz. G. Richard. 12¾ pp., 14 illus. Discussing hand regulation, thermostatic regulation and types of regulators, position and advantages : *Chauffage-Ventilation*, December 1933.

Refrigeration. 621.564

Water in Refrigeration. Walter L. Fleisher. 8½ pp., 21 illus. Dealing with influence of its quality and temperature, city water problem and its use as a refrigerant : *Refrigerating Engineering*, January 1934.

Air. 533·3

Diurnal and Seasonal Variations in the Small-Ion Content of Outdoor and Indoor Air. C. P. Yaglou and L. C. Benjamin. 7¾ pp., 6 illus. Results of research on diurnal and seasonal variations and changes taking place in lightly occupied rooms : *Heating, Piping and Air Conditioning*, January 1934.

Electricity. 537·1

Electricity Facts. R. C. Allen. 4½ pp., 9 illus. Defining terms used in electrical work : *Domestic Engineering*, December 1933.

Fans. 622.445.6

Industrial Fan Drive Applications. Robert W. Drake. 4½ pp., 8 illus. Describing application of V-belt, flat belt and chain drives for industrial fans : *Heating, Piping and Air Conditioning*, January 1934.

Air Conditioning. 697.96

Low-Cost Air Conditioning for a Small Residence. M. K. Drewry. 7¾ pp., 9 illus. Describing installation, design, tests and operating experiences, special tests, cooling experiences and annual cost : *Heating, Piping and Air Conditioning*, January 1934.

Fuel. 621.22

The Meaning of Coal Analysis. Clarence A. Seyler. 3 pp., 1 illus. Dealing with carbon and hydrogen basis, relationship of volatile matter to composition and bituminous coals : *The Fuel Economist*, January 1934.

Drying. 634.9

Principles of Drying. C. W. Ulett. 4 pp. Describing terms and dealing with heat, vapour and air as a heat vehicle and drying medium : *Heating and Ventilating Engineer*, January 1934.

Heat. 691.951, 536

Thermal Insulation. Eżer Griffiths. 7 pp., 5 illus. Dealing with determination of thermal conductivity by the buried sphere method : *Heating and Ventilating Engineer*, January 1934.

Steam Heating. 697.52

What Size Piping for One-Pipe Steam System. Wm. W. Stevens. 2 pp., 3 illus. Dealing with sizing with use of tables : *Domestic Engineering*, January 1934.

Hospitals. 725.5

Engineering Economy in Hospital Design. Charles F. Neergaard. 6 pp., 4 illus. Dealing with heating, ventilation, air conditioning and operating the plant : *Heating and Ventilating*, January 1934.

Air Conditioning. 621.564

Air Conditioning for Heating Contractors. D. E. Perham. 5½ pp. Dealing with equipment for mechanical refrigeration, reciprocating compressor systems, centrifugal and rotary compressors, drives and safety operations and fire rules : *Bull. Heating, Piping and Air Conditioning Nat. Assoc.*, January 1934.

INSTITUTION OF HEATING AND VENTILATING ENGINEERS

REPORT

SESSIONAL MEETING, LONDON, MARCH 7th, 1934

SESSIONAL Meeting of the Institution was held in the Lecture Hall of the Home Office Industrial Museum, Horseferry Road, Westminster, S.W.1, on March 7th, 1934, Mr. R. Comyn Ching, President, in the Chair.

There were about forty present and the following signed the attendance register: Messrs. W. E. Brown, L. A. Forni, N. E. Jackson, T. H. S. Hatchett, E. L. Joselin, C. S. K. Benham, H. C. Bailey, A. Fleming Browne, Alcwyn A. Jones, H. Leslie Egerton, J. W. Stitson, J. N. Bottrill, J. H. Eusom, L. A. Baines, R. C. Ching, A. J. Burton, F. F. Mudie, Geo. F. Rider, T. G. Connor, H. R. Henderson, T. E. Barnes, Geo. A. Pullen and H. B. Watt (Secretary) (London); Wm. H. Turvill (Tunbridge Wells); C. M. Oates (Manchester); and the following visitors: H. C. Green, Robt. B. Grey, E. W. Murray (London); A. F. Dufton (Garston); A. J. Newport (St. Albans).

The President, in introducing Mr. R. B. Grey, the author of the paper, said the members had before them a most interesting paper dealing with a subject of extraordinary interest and importance to all heating and ventilating engineers. As most of the members knew, heating and ventilating engineers had many troubles connected with noise, and the more they could learn about its cause, the way in which it was to be measured, the reason for it and its cure, the better.

He had great pleasure in introducing the author, who was an expert in, and who had had a vast experience of, this particular matter of noise connected not only with the heating and ventilating industry but with many other industries.

He then called upon Mr. Robert B. Grey, A.M.I.Mech.E., M.I.P.T., to read his paper on "The Prevention of Vibration and Noise in Heating and Ventilating Systems."

THE PREVENTION OF VIBRATION AND NOISE IN HEATING AND VENTILATING SYSTEMS

By ROBERT B. GREY, A.M.I.Mech.E., M.Inst.P.T.

SESSIONAL MEETING, LONDON, MARCH 7th, 1934

THE installation of heating and ventilating plant in the modern building has increased the comfort of the occupants beyond all measure, but in its wake it has brought troubles in the form of transmitted vibration and noise. It is the elimination of these troubles with which this paper is concerned.

The principles and methods employed are the outcome of twenty-two years' experience in dealing with problems arising out of these troubles.

During that period, all manner and descriptions of machinery has been dealt with, and almost every machine is a problem in itself to be considered separately from all others.

The problems arise in devising methods of application of the principles involved, based on a wide and varied experience gained in the past.

It stands to reason that although the principles are the same their method of application must vary with the type of machine, thus the method of application to a steam hammer must differ from that of a motor-driven fan or a motor generator from that of a pump.

It is in the methods of application of principles that experience helps to avoid pitfalls and ensures a successful result.

One would be correct in stating that all moving machinery creates vibration and noise, more or less, but it is only the machinery creating a nuisance with which we are concerned.

In connection with vibration and noise, heating and ventilating engineers are, as a rule, in an unhappy position because their plant is so often installed in buildings of such a character that silence is absolutely essential; not just what might be termed reasonably silent, but dead silence, that perfect silence in which the proverbial pin is heard to drop.

This perfection of result, from a vibration and noise point of view, is in such request that consulting engineers now embody in their specifications, demands for special anti-vibration and noise equipment in connection with the installation of heating, ventilating, and other machinery usually installed in up-to-date buildings.

The information contained in this paper will possibly be of some assistance in meeting these demands and also probably help those responsible for drawing up specifications to define clearly their requirements.

Definition of Terms.

Before proceeding further it will be as well to define some of the terms used in connection with vibration and noise.

Vibration is defined as those vibrations having frequencies below 50 per sec. and perceptible to the senses as movement.

Noise can be defined as those vibrations having frequencies above 50 per sec. and perceptible to the sense of hearing.

Amplitude is the range of movement of a body on each side of the mean position. In this paper, measurement of amplitude is the full range of movement and not the half amplitude as sometimes expressed.

Period is the time to complete one vibration.

Frequency is the number of vibrations in one unit of time usually either one minute or one second.

Natural frequency is that frequency at which a system will vibrate of itself after having been set in motion. Thus, if a weight is suspended from a spring and the weight is pulled down and released, it will continue to move up and down or vibrate at the natural frequency of the sprung weight, until its energy is damped out.

Resonance is the synchronising of the frequencies of two systems. Thus, if a machine vibrates with a frequency of 10 per sec. and is mounted upon a floor having a natural frequency of 10 per sec., then the floor will vibrate heavily under the influence of the vibration of the machine and is said to be in resonance with its frequency.

Vibration may be divided into three classes :—

Foundation vibration.
Primary or direct air vibration.
Secondary air vibration.

Foundation vibrations are those produced in the foundation by the machine and may be either high or low frequencies or more often a combination of both.

Foundation vibrations set the whole of the surroundings into movement at the same frequency and by moving the floors and walls of a building, set the air in contact with these into vibration at the same frequency; these air vibrations are defined as *secondary air vibrations*. If the vibration set up by the machine is of high frequency creating a hum or noise, this will be heard throughout the building through the medium of secondary air vibrations.

Primary air vibration is transmitted from the machine directly through the air and will be heard as noise in the room and through openings such as doors, windows, ventilators, etc., and a proportion through the walls, depending upon their construction.

Secondary air vibration is the movement of the air set up by the vibrating floors and walls or body of a structure which, if the frequency is sufficiently high, will be heard as sound.

For the purpose of isolation, machinery can be divided into three classes :—

(1) *Rotary machines* such as turbines, motor generators and similar plant.

(2) *Reciprocating machines* as steam, oil, and gas engines, printing presses of the flat-bed type, guillotines and various industrial machines.

(3) *Impact machines* as the steam and drop hammer, flypresses, foundry jarring machines, and of course there are numerous combinations of all types.

There are two problems to be considered in preventing the transmission of vibration and noise, first, preventing the transmission of the low frequencies of vibration below 50 per sec. Secondly, preventing the transmission of the higher frequencies of noise, viz., those above 50 per sec. The methods used for preventing the transmission of the low frequencies is also useful in preventing the transmission of the higher frequencies.

General Principles.

The general principles involved in isolating machinery are as follows :—

First, that the vibrating machine shall be mounted upon an elastic medium so that the free energy or vibration is dissipated in internal friction in the supporting medium, allowing the machine certain freedom of movement.

Second, the supporting elastic medium must have a natural frequency, under its load, below any frequency of the machine.

Third, particularly applied in cases of high frequencies, is that there shall be no direct metallic or rigid contact between the source of noise and the floor or walls.

These three principles are broadly applied to all machinery to prevent the transmission of vibration and noise to the surroundings.

In an isolated system, forced vibration of high frequency has little effect upon a system having a low natural frequency, thus a forced vibration, say from an unbalanced motor and fan-runner having a frequency of 1,500 per min, if mounted upon a system having a natural frequency of 150 per min. will have little effect upon the system and little or no vibration will be transmitted.

If, on the other hand, a forced vibration having a frequency of 150 per min. is mounted upon a system having a frequency of 1,500 per min., then the system has little isolating value and vibration will be transmitted. All systems have a natural frequency of their own and will pick up and respond to an incoming similar frequency transmitted from some remote machine, frequently amplifying it to cause a nuisance.

The system is then said to be in resonance with the incoming vibration.

The effects of resonancė is at all times difficult to overcome.

Resonance may, and frequently does, occur between some period of a fan-runner and fan-casing or between the hum of a motor and a beam or floor in a building which partly accounts for the fact that noise is sometimes more noticeable in some part of a building quite remote from the machine.

Isolating Materials.

An isolating material for supporting a machine should have the following properties :—

Permanent elasticity.

Capable of sustaining the loads imposed upon it.

Should not be detrimentally affected by oil or water.

Durable.

Reasonable in price.

Many materials are in use for supporting machinery such as cork, in several forms, felt, jute, rubber, etc.

As an isolating medium for primary air vibration or direct noise from a machine, there are also large numbers of various materials such as various fibreboards, eel grass quilting, asbestos felt, strawboard, etc. As a machine support and an isolator of high frequencies, I believe cork in its natural form to be one of the best, if not the best, form of resilient material to use for the purpose. I have used this on a great number of installations with excellent results. A combination of layers of special felt and cork will give even better isolating results, the variation in densities retards the progress of noise through the layers.

Whilst this combination of materials, or practically any combination of resilient materials reduces the transmission of sound, they often fail to effect noticeable reduction in the lower frequencies of vibration and under resonant conditions will actually amplify it.

Natural cork in steel frames has a frequency of about 1,200 per min. under a load of 5 lb. per sq. in.—if a fan or pump running at 1,200 r.p.m. is mounted upon cork having a loading of about 5 lb. per sq. in., it will most certainly amplify any vibration set up by the machine, and this applies similarly to any system mounted upon an elastic medium where the load per sq. in. causes the natural frequency of the system to coincide with some frequency set up by the machine.

This fact limits the use of these various resilient materials and has resulted in the application of spring devices as a supporting medium.

A spring can be designed to have any pre-determined frequency below that of the machine, thus satisfying the second principle and I have found that a combination of springs, felt and cork, give the best results in preventing the transmission of the low frequencies of vibration and the higher frequencies of noise.

Anti-vibration Devices.

The anti-vibrator is a cast-iron housing in two parts—an upper and a lower half—inside the housing is arranged a spring or series of springs and pads according to the load to be carried.

Adjusting screws are provided to regulate the compression of the spring and provide damping effects.

The lower half is secured to the floor and the upper half to the machine base and the number used to support a machine depends upon weight and dimensions.

These anti-vibrators have been successfully used to isolate all manner and descriptions of machinery.

Method of Application.

The following is an ideal arrangement for a motor-driven fan installed on a roof or an upper floor :—

The motor should not be directly connected to the runner shaft, but the drive should be through a belt preferably of the " V " type.

The motor should be mounted upon a suitable number of anti-vibrators secured to a concrete slab, this would also support the bearings, runner shaft and runner.

The concrete slab should be isolated from the floor with 2½ in. cork in steel frames and felt ½ in. thick.

The fan-casing is isolated at the base with cork and felt and the casing must not be in contact with the concrete slab or any part of the isolated foundation.

The inlet and outlet ducts of this fan to have flexible lengths inserted—these lengths should be made of light canvas or leather—it is important to have these very flexible in cases where the ducts are made of light gauge sheet metal.

In order to reduce transmission of noise from the fan-runner directly through the ducts, the inside should be lined with a sound absorbent material to reduce the reverberant effect of plain metallic surfaces.

If the distance between the plenum fan and the ventilating outlet points in, say, a theatre is short, then noise can be effectively reduced by leading the air into a large baffle-box fitted with a number of baffle-plates each baffle lined with sound absorbent material. This box, which should have a large sectional area compared to the ducts, acts as a receiver and silencing chamber, the ducts leading from this chamber to the outlet points in the theatre.

The penetrating noise from rotary converters has been successfully extracted from the air stream, used for cooling purposes, before it left the sub-station by using properly designed baffle-chambers.

Air-conditioning Plant.

This type of plant usually includes refrigerating plant with its accompanying compressor, both rotary and reciprocating type.

These compressors may, of course, be driven by any form of prime-mover, but usually an electric motor is utilised.

If the compressor is of the reciprocating type—vibration is likely to predominate and the most effective method of isolation is through the medium of springs.

It is advisable to mount the compressor and its motor, whether direct-coupled or belt-driven, upon a suitable reinforced block of concrete. This concrete foundation is supported by means of suitably arranged steel joists embedded in the concrete, the ends of which project beyond the concrete and rest upon or are attached to a series of anti-vibrators, or alternatively, a patented arrangement of laminated springs and dampers.

In an isolated foundation of this description it is most important to design the sprung foundation to have its frequency well below the lowest frequency set up by the reciprocating compressor.

A foundation isolated in this manner against the comparatively low frequency of rotation also prevents the transmission of the higher frequencies of noise.

Rotary compressors have also been successfully isolated in a similar manner on springs.

Washing Equipment.

The washing chamber should be isolated from the supporting floor by means of pads and felts to prevent transmission of the noise of the sprays to the supporting floor and thence to the building. The washer pump should also be isolated in common with the rest of the equipment.

Recently the noise of a washer spray created a nuisance and could be heard emanating from the intake end of a fan duct which projected above a row of residential flats—this was effectively overcome by lining the whole of the duct with sound absorbent material, this eliminated the reverberation in the duct and its consequent transmission outside.

Pumping Plant on Heating Systems.

In general, the methods applied to fan equipment are equally applicable to pumping plant, such as accelerator pumps on both heating and domestic-supply systems.

In the first place, referring to pumps of the centrifugal type, it is generally necessary to isolate completely the motor from the pump in order to prevent transmission of hum into the water lines and consequently into the building, this precaution is essential in A.C. motors, particularly if on single phase.

Once again it is better to drive through a belt in preference to direct-coupling. The effective isolation of the motor under these conditions presents little difficulty.

The motor is mounted upon anti-vibrators so designed that they make provision for the belt pull. These effectively prevent transmission of vibration and noise from the driving unit. The pump, on the other hand, is not quite so easy to deal with on account of its direct connection with the water—water readily transmits sound at the rate of 4,500 ft. per sec., consequently a badly designed centrifugal pump impeller on quite a small pump will create a nuisance throughout a large building.

The metallic continuity of the pipe-line can be readily broken by inserting a length of rubber piping—this can be reinforced to stand up to the head on the line, but up to the present no effective method has been devised for eliminating noise in a pipe-line set up by a faulty impeller.

All pipe-lines leading to and from the pump should be kept clear of direct contact with walls and all parts of the building. In all systems isolated to eliminate principally the transmission of noise it is essential to see that all points of contact between the noisy section and the structure of the building are efficiently isolated. Each small contact contributes its quota of sound and only by avoiding these direct contacts can noise be effectively eliminated—a single point of contact may not amount to much, but in the aggregate a number of small contacts may produce sufficient noise to create a nuisance. As a simile, a field of buttercups is a blaze of yellow and the removal of one or two makes no appreciable difference—but if one keeps on removing them, the yellow blaze gradually disappears; so it is with sound and points of contact, however small.

Oil Burners.

The burner unit should be isolated from the floor and all pipes have flexible lengths—the burner duct leading into the furnace front should pass through a sleeve allowing an annular space of, say, 1 in. between the duct and the sleeve, this space should be packed in with 1 in. asbestos rope similar to a stuffing-box.

Boilers.

These are usually mounted upon suitable helical springs to prevent the roar of the burners being transmitted *via* the boiler shell to the structure of the building.

Heating and ventilating equipment installed on these lines should give no trouble from transmitted vibration and noise always assuming that the walls are of reasonably solid construction to resist the transmission of primary air vibration.

Instruments for Measuring Vibration and Noise.

Very sensitive instruments are in use for the measurement of vibration, examples of which are on exhibit. These vibrograph instruments are made by the Cambridge Instrument Co. and are on the seismograph principle—they produce records on celluloid strip which are photographically enlarged usually by 100, enabling frequencies and amplitude to be readily inspected.

These are most useful in designing isolating equipment as they disclose exactly what is taking place. They also afford means for comparison before and after a machine is isolated. In cases of nuisance and pending litigation they afford evidence of the existence or otherwise of vibration, indicating its amplitude and frequency.

Noise is measured by means of the acoustic meter, a product of the Standard Telephone Co.—this is a comparator instrument producing a tone, a comparison of which, with an external noise gives a direct reading in decibels of the intensity of the measured noise.

This instrument is also a useful means of gauging the effects of isolating a machine.

Summary.

In ventilating equipment the motor should be carefully separated from the fan-casing and runner and properly isolated.

The fan-casing and ducts should be separated by flexible non-metallic lengths.

Air speeds and speed of rotation kept as low as possible.

Pumps and motor should be separated, belt-driven, and isolated.

Pipe contacts should be isolated from the building.

Refrigerating plant should be isolated on springs and all direct contact between any part of the plant and the building avoided so far as practicable, and always remember, previous to installation that, "Prevention is cheaper than cure."

DISCUSSION.

Mr. Alcwyn A. Jones thanked the author for his very interesting paper, which had given the members much food for thought; they seemed to be between the devil and the deep sea—or, speaking technically, between vibration and noise—as a person with normal hearing could hear sounds ranging from 32 frequencies per second to 15,000 frequencies per second. The author classed as " vibrations " frequencies below 50 per second, and " noise " as frequencies above 50 per second. Consequently what could not be heard could be felt, unless the equipment was tuned to frequencies of over 15,000 per second.

Noise played strange tricks with heating and ventilating engineers. Recently he had gone over a building, with pump circulation, to see whether the motor hum was audible. Near the boiler room it had been audible. Other rooms were noise-free. Yet when he had reached the farthest room the noise had again been audible. Perhaps the author could give some explanation of that.

There was no denying the necessity of eliminating noise and vibrations, and the paper gave helpful information in that connection. Noise must be dealt with at its source if anything really effective was to be done about it, and the instrument described would be one by which it would be possible to locate the actual source of noise.

Was it possible, in ventilation, to eliminate the sound caused by the action of the fan-blades on the air?

Dealing with pumping plant on heating systems, the author stated that water readily transmitted sound at the rate of 4,500 ft. per second. Did that mean the velocity in the pump or the rate at which the sound travelled, because noise was audible in pipes where the water had a velocity of 3 or 4 ft. per second?

The author stated that all pipe-lines leading to and from the pump should be kept clear of direct contact with walls and all parts of the building. Personally, he did not see how that was a practical proposition, because the pipes must be clipped or stayed to the building.

When dealing with instruments for measuring, the author mentioned that one instrument gave direct readings in decibels. The other day he (Mr. Jones) had been asked by a member what a decibel was because he had received a specification stating that noise was not to exceed a certain number of decibels. He mentioned that in his own opinion a decibel was a unit of loudness. Since then he had learned that the human ear did not respond to the intensity of the sound, but rather responded to the logarithm of intensity. The decibel could be expressed as $10 \log_{10} \frac{I_1}{I_0}$, where I_1 and I_0 were two intensities, I_0 being the intensity from which the loudness of the sound was measured, and was taken as that which was just barely audible in an absolutely quiet room, and was represented by zero on the decibel scale. Perhaps the author could define the decibel in a simpler form.

Could the author supply a table of standard decibels for various types of buildings so that the intensity could be specified? According to the American Heating and Ventilating Engineers Society's Guide the proper standard for office buildings was about 25 decibels, while in a space where quiet was of importance the level should be as low as 5 decibels.

A common source of trouble was the motor-shaft being slightly out of true, which would cause vibrations. Could the author give a reason for a cork insulation under a motor becoming compressed and throwing the shaft of the fan-runner out of line and, when renewed, the same thing happening again?

Mr. George A. Pullen also thanked the author for preparing and reading his valuable paper and for bringing along so many interesting slides. He also expressed his disappointment that the meeting was so poorly attended, because the paper was of very great importance to the heating engineer.

The author had concluded his paper by saying that prevention was cheaper than cure, which, while always true, was especially the case when it came to the question of the prevention of noise and vibration. It was very often found that where, say, a pump or fan had to be installed in a building where silent running was of the utmost importance little or no precaution was taken to insulate or isolate such machinery from the building.

As the author stated, the modern type of building was particularly liable to transmit and amplify sound. He had known of a case in which some really super-silent pumps and motors were installed in a large block of flats, but a complaint arose that a very objectionable noise, like the hum of a badly oscillating wireless set, could be heard on the third and upper floors. The cause of the trouble was traced to the no-volt coil on one of the starters, which was fixed directly on to the wall of the pump-house and wired-in steel conduit which had been embedded in the wall. The starter was isolated from the wall, the conduit dug out of the plaster and the noise absolutely disappeared.

The author stated that precaution was essential in A.C. motors, particularly if of single phase. Nowadays, there were several manufacturers who could turn out really silent polyphase motors and he was also glad to be able to inform the members that he had recently found a firm who could turn out really silent single-phase motors. Two 4 and two 2 h.p. direct-coupled pumps and single-phase motors had been installed in a hospital in Kent and the contractors' foreman had reported that he actually had to touch the machines to know which one was running. A higher degree of silence could hardly be required and if in hospitals, flats and like buildings, where the prevention of noise and vibration was of the greatest importance, one chose machines of such standard to start with and then took some precautions to insulate in case the building had amplifying qualities, not perhaps with elaborate cantilevers and springs, but with some decent insulating material properly designed and calculated to carry the weights required, a great deal of trouble and expense could often be avoided.

He recalled that a business friend of his had ordered a second-hand pump, had coupled it to a super-silent D.C. motor on a light welded-steel base and as the set had to be fixed on a hollow tile floor on the top of a council chamber he had placed some ¼ in. thick sorbo-rubber underneath the base, but had had it bolted down so tight that the rubber had no further resilience. If he had taken a moment to consider he would have realised that such insulating material was entirely unsuited for the weight it had to carry, although it was of the utmost importance that the job erected on the top of a borough council chamber should be really quiet.

He suggested that the advice of the author or of somebody equally qualified should be taken on these sound and vibration reducing and isolating questions. He instanced a case where a friend of his had ordered a couple of large slabs of insulating cork, 2 in. thick, the full size of the baseplates for two big pumps ; he would have been far better off by having only eight small slabs, one for each of the corners of the bases, as by using it as he had his friend was losing at least 90 per cent. of the material and had failed to get the weight properly distributed, in fact, if he had asked advice instead of sending an open order for these insulating slabs he would not only have saved a lot of money but have done the job very much better.

He did not think one needed to go to the extreme which the author suggested in his summary, viz., that pumps and motors should be separated, belt-driven and isolated, because it should be remembered that a pump itself could be the cause of noise, and isolating the motor from a noisy pump was not going to prevent such noise from being transmitted throughout the system by the water and the piping, and even the building itself.

Even where a silent motor and a well-designed centrifugal pump with an impeller, shaft and coupling in true static and dynamic balance was installed he had known cases where the pump was connected to too small diameter piping and velocity noises set up that were carried right through the system. A pump which would handle, say, 80 gallons per minute efficiently might have only 2 in. branches, but the pipe size should be increased to reduce the velocity from nearly 10 ft. per sec. to say the more reasonable figure of 5 ft. per sec., which should not be exceeded on pipes smaller than 3 in. diameter where velocity noises would be objected to.

One thing which the heating engineer often forgot was that velocity noise once started was amplified again by sudden sharp changes in the direction of flow. Personally, he would like to see sharp elbows and tees abolished on heating jobs where silence was required. Easy bends, large pipes, low velocities, some insulating probably, and a good motor were the real essentials—and a little advice in case of need.

Mr. C. M. Oates asked the author if he had ever had any experience in connection with stopping noise from gas boilers. There was a certain type where the burner was 4 in. from the tubes, and caused considerable noise.

Mr. E. L. Joselin joined with other speakers in thanking the author for his paper on the subject of the prevention of vibration and noise in a building. He had been personally first brought into contact with the subject about 25 years ago when some ventilating fans had had to be put on a roof. No thought had been given to the point of preventing noise getting in, but when the fans had been put up and provisionally put to work it had immediately become apparent to people in the building that there was going to be some trouble. The noise of the fans (not much noise but simply a slight noise), and their position on a hollow roof, was going, it was evident, to make a noise in the building. Something had had to be done in a hurry, and someone had got some very heavily made coconut door-mats and put them together face to face under each fan. Personally he did not know whether that person had used two mats or four mats underneath each motor and fan ; but the benefit of the material was that it stood dampness and weather—as everyone must know from its use by sailors for fenders for taking the shock of the boat coming against the wharf. That method had been perfectly successful. How long it had lasted he did not know, as he had not had any opportunity of seeing it recently. He would like to know if the author had any experience of it.

If the members would forgive him mentioning an incident, they had had an experience at the Institute some years ago of a very curious transmission of noise. Before the Borough Polytechnic had been rebuilt they had had their own engine—a little vertical steam-engine and generator of about 50 kW. That was moved from one position to another at a certain date, and when it had been set to work, a room in a part of the building, quite a hundred yards away (at the far corner of the building as a matter of fact), became impossible to occupy. It had a door and two or three windows which started to rattle so violently that one could not hold a class in it without opening the door and without wedging the windows. There was no noise in between at all. That noise, it had been discovered afterwards, had simply been transmitted through the foundations in a curious way.

There were two other points he would like to mention. One was the question of the noise of water flowing through a pipe. When a certain velocity was reached (which he was not prepared to name) water did make a noise simply by turning the bends, and so forth, in a pipe, quite independent of any noise that it might have had in it through the pump. It would be interesting to know what limiting velocity should be worked to, and what sharpness of bend —or, rather, what absence of sharpness of bend—was necessary to prevent such noises occurring.

Then there was the subject of the noise of air flowing through a pipe. With certain arrangements of dampers if the air had a certain velocity a swishing noise resulted which, once started, did not die away, and that was transmitted for quite long distances.

There was another point where air noise occurred. There were some cases where one had a centrifugal cased fan and it was delivering a certain volume of air, but it was liable to have its outlet cut off by dampers, so that on certain occasions very little of the air was being sent through the duct-work at all. Most centrifugal fans in a case like that had a back draught through the inlet, and that back draught created a terrific noise. Had the author come in contact with that and, if so, how had he dealt with it? The point was interesting to him personally as he had come in contact with it so many times.

Mr. A. F. Dufton remarked that after the most interesting exhibition of slides and the very lucid description of the matter given by the author it might perhaps appear rather unkind to be at all critical of the paper, but there was one point to which he thought attention should be drawn, and that was the definitions given by the author of *vibration* and *noise*. The author's definition of *noise* as " those vibrations having frequencies above 50 per sec. and perceptible to the sense of hearing " hardly accorded with the view that noise was merely unwanted sound. These definitions tended to obscure the author's meaning, for he sometimes used the terms in their common significance, *e.g.*, " Primary air vibration is transmitted from the machine directly through the air and will be heard as noise." This does not mean that frequencies below 50 per sec. are heard as frequencies above 50 per sec. Before the paper was printed in the *Journal* perhaps the author would like to reconsider his definitions.

One point on which he felt strongly was that in the attempt to prevent noise the great thing was to go right back to the source. It paid much better to get really silent gear than to get gear which was not silent and then try to cure the trouble.

What the author termed *primary air vibration* could be got rid of in some cases by screening. The noisy piece of mechanism was boxed in with some acoustic material, and the vibration was prevented from getting away.

Where pipes passed through walls it was rather important to see that the holes which were made through the walls were properly stopped up ; otherwise air-borne sound would pass through the holes. There were two problems—one was to prevent the pipes from shaking the walls, and the other was not to leave a gap in the walls through which air-borne noise could penetrate.

Mr. Geo. F. Rider said the point had been raised, in connection with the plant a photograph of which had been thrown on the screen, that it was essential, after a machine had been mounted on an insulated base, to have the machine provided with connections which were flexible. One of the slides which had been thrown on the screen showed a rotary compressor with metal flex connections in the pipes, and to him they seemed to be exceedingly short. He did not know whether that was intended to be an example to the present meeting, but if that metal flex was of a strength that had to carry steam he was very doubtful himself whether a short length like that would be really effective. Probably in the case of rubber connections on accelerators it would be quite satisfactory, but he did not think from his own experience that very short connections like that in metal flex would be really good.

Another point was whether, in seeking to break the metallic connection and make indirect drives by means of belt connections, fresh trouble to a certain extent was not being brought in by introducing side stresses in the bearings which would not exist in a direct-coupled set, and whether there was any possibility of getting a really flexible covering which would relieve one of any belt pull. He did not know what the comparative merits were, but it was a point which might cause trouble on some machines—the side-pull of the belt.

Mr. E. W. Murray referred to a case in which noise insulation had been applied unintentionally. The firm concerned were making hemp ropes, and the number of bobbins broken from falling on the hard floor was a continual source of expense. They had a stock of old ship's rope in store and decided to coil and fix this rope to the floor. This considerably reduced the breakage of the wooden bobbins and incidentally caused a reduction in the volume of noise in the factory.

The President, Mr. Ching, said the members had listened to a very instructive paper, and the discussion on it, as was usual at the Institution's meetings, had brought out very many points of interest.

There was one question which he desired to ask. The author mentioned natural cork having a frequency of about 1,200 per min. under a load of 5 lb. per sq. in. and went on to say " If a fan or pump running at 1,200 r.p.m. is mounted upon cork having a loading of about 5 lb. per sq. in. it will most certainly amplify any vibration set up." That speed was quite a usual speed for pump running, although the load of 5 lb. per sq. in. might be rather small. Could the author tell those present how to determine when to use cork on an apparatus of that kind. If they were using cork should they alter the load from 5 lb. to something more, or to something less, in order to prevent that amplification of vibration?

Another thing he should like to ask was in connection with flame roar particularly on oil-burners. Oil-burners could be, and were, designed which were fairly silent of themselves, but there was always the difficulty of the flame roar inside the furnace, and it was very difficult to eliminate that flame roar. In his own opinion the flame roar was largely one which was transmitted through the air into the boiler-house, and from the boiler-house sometimes to other parts of the building. On one occasion that noise had been prevented to a very large extent, or it had been damped down, by lining the walls of the boiler-chamber with something which he understood was sea-weed. It might have been the eel grass quilting to which the author had referred. But it was a difficulty which heating engineers frequently came across.

He thanked the author for his excellent paper and for the great amount of information contained in it.

Mr. R. B. Grey, in replying to the discussion, said with regard to Mr. Jones' remarks, that the figure of 50 frequencies per sec. was a purely arbitrary one. He believed it was scientifically recognised that frequencies from about 30 per sec. up to 20,000 per sec. were audible. Personally, he had taken 50 per sec. as a practical base line. He might, however, not be scientifically correct in doing so.

Mr. Jones had mentioned a case where the noise from the motor had been heard in a remote part of the building, whereas in other and nearer rooms it had not been heard. It was quite possible that that was due to a resonant effect at that end of the building, vibration being picked up by a beam or floor which was in resonance with the vibration coming in from the motor and amplifying it, other parts of the building not being in resonance would not respond.

So far as tracing the source of sound was concerned, he thought it would be found that a tectophone was a very good form of instrument, one end is placed to one's ears and the other placed in contact with pipes or walls until the source of sound is traced.

Velocity of sound through water flowing through a pipe was very much the same as sound passing through the air. It would increase with the direction of flow and decrease against the flow, but the sound would travel whether the water was moving or not. As a simile, if there was a wind blowing towards one, from the direction of the source of sound, the sound would be heard very distinctly. If one went the same distance away on the other side of the source it would not be heard so distinctly.

With regard to the clipping of pipes, all clips should be isolated. When he referred to keeping a pipe from contact with a building he was not suggesting suspending the pipe in the air. The pipe had to be held in position, but some sound-resisting material ought to be interposed between the rigid support and the pipe.

Coming to the definition of " decibel," he thought the term had come over from the U.S.A. and it was defined as the minutest increase in sound which could be possibly detected by a human ear. He did not know how one was going to determine what constituted the minutest intensity because it appeared to depend so much upon the keenness of hearing of the observer. He had had a case where litigation had been pending between an old lady who lived four or five storys up in a building and the owners of a freezing plant which was installed in the basement, and suitably isolated. He had tested with a tectophone in the lady's flat and could not detect any noise whatsoever from the plant and nobody else present could, but the lady insisted that she could hear the machine. He had therefore set a trap for her. He had timed his watch with the operator's down below, and it had been agreed between them to stop and start the freezer about every two minutes. He had gone up to the flat and had not been able to hear the freezer and he had asked the lady if it was all right. The lady had replied that it was. Then she had suddenly said " They have started it again," but he could not hear it. He looked at his watch and found that it was due to be running, and it had been running. How was one to fix a decibel under such circumstances of hearing as those? It made him doubt the reliability of the decibel unit.

With regard to Mr. Jones' point about the settlement of some cork under bearings, personally he should say that it was probably due to faulty design. If that isolated system had been designed correctly the centre of gravity of the whole would be over the centre of support, and one would not get uneven settlement, and if it went down bodily it was obviously overloaded. It was purely a question of correct design and layout.

He had been asked if there was a table of decibel standards for various buildings. He was not in possession of one, but he had seen some tables drawn up by some acoustical experts. He did not consider himself an acoustical expert.

Mr. Jones said there was a table in America.

Mr. Grey said there had been a table brought out dealing with decibel measurements ranging from a pneumatic hammer and an aeroplane down to a whisper in a garden, but he did not think there had been any definite table got out to show that an office should not exceed a definite number of decibels. He recently had a specification put up to him limiting the amount of noise to 52 decibels, but that appeared to him to be a considerable amount of noise. The other day he had been taking measurements of noise in a power-house containing a lot of Diesel engines running, the noise at the far end of the building was as loud as it had been against the machine, but intermediately it was 10 decibels less, therefore, when 52 decibels was specified as a limit, in what part of the room were they to take measurements? This point he considered should also be indicated in specifications embodying measurement of noise.

Mr. Pullen had referred to silent motors. Personally he wished he knew where to get them. He would ask Mr. Pullen afterwards. With regard to isolating full areas under a machine, full area, nine times out of ten, was not desirable under any machine on account of the low load per square inch on the material.

He was afraid he had had no experience with gas boilers, but he would suggest that the same treatment to a gas boiler as applied to an oil-burner might be serviceable.

He had seen coconut mats under quite a number of machines—some had good results and others not. Sometimes there might be a case where the coconut mat under its load might be in resonance with the machine itself and vibration consequently amplified. At other times they happened to be clear of resonant periods. Personally he should not like to specify coconut matting for isolating purposes. He should prefer to see something more mechanical, the compressibility and frequencies of which were known.

With regard to noise in water pipes, he thought that was bound up with turbulent flow and stream-line flow. One got a change over from stream-line flow to turbulent flow when a certain velocity of flow was reached. As soon as one got the latter there was not only an increased load put on the pump, but an increased noise in the pipe-line. The bends and tees would also set up additional noise.

He had not come across the particular trouble mentioned about back-draught noise from the fans.

With regard to Mr. Dufton's remarks about the definition of "noise," that was bound up with his first query about the 30 frequencies per sec. He did not quite follow Mr. Dufton's meaning. When he (Mr. Grey) said "noise" he was referring to sound, with a definite frequency or a noise made up of indefinite frequencies—he might be dealing with a 50-cycle hum from a motor or with a noise from a pneumatic hammer—having quite different characteristics, but they might both have the same intensity. He was afraid he had not grasped Mr. Dufton's point.

Mr. A. F. Dufton said that "noise" was a good English word, and one could look it up in a dictionary, but one would not find the author's definition, or anything like it. Nor would one find the author's definition of "vibration."

Mr. Grey said he had tried to make a practical definition of the difference between vibration and noise for the purposes of isolation. Broadly he defined vibration as perceptible to the senses as movement and noise that which was perceptible to the sense of hearing. Vibration could be felt: noise could be heard. Noise, however, might be also felt if sufficiently intense.

Mr. Dufton asked the author if he really used his definitions. Were they of any help in the elucidation of the paper?

Mr. Grey replied he hoped they were.

Mr. Dufton said they did not help him.

Mr. R. B. Grey said he might try to evolve a better definition. He had erected sound-proof cases round machines on many occasions, but a sound-proof case around a machine which was not isolated was of little value. Only recently he had had a case of a mill which was used for making cattle food running at a high number of revolutions and situated over some offices. The offices had been isolated by lining the ceiling and walls with sound-resisting material, but it had not made the slightest difference because the mill was in direct contact with the building. As soon as the mill had been isolated the noise disappeared. The machine must be isolated first and then a sound-proof case erected around it.

With regard to the remarks made about pipes in direct contact with the building structure, he had always assumed that it was understood that an isolating medium should be placed between the wall and the pipe, or the clip which was holding the pipe.

Somebody had raised a question about flexible connections. Those were really to stop transmission of vibration along the pipes; a number had been working for seven or eight years and were still functioning perfectly.

With regard to the effect of belt-pull and pump bearings, one assumed that the bearing of the pump was designed to take the side pull. He had tried a number of different types of flexible couplings in direct-coupled sets and frequently had trouble by their getting out of alignment. He had used the flexible-disc type as well as rubber-lined couplings, but he did not consider anything could better a belt drive to prevent transmission of noise between the motor and the pump.

With regard to the President's remarks on the frequency of cork, the frequency had been determined by compression tests on the cork, and cork had been mathematically considered as a spring and the same formula used to determine the frequencies. In referring to 1,200 r.p.m. and 5 lb. per sq. in., one frequently got 5 lb. per sq. in. load on the base of a normal bed and it was better to reduce the area and increase the load per square inch and to keep the frequency of the whole system below that of the machine. If one had a machine and the full area of the base had been isolated with cork, personally he would take it out and cut up the cork into small sections, place it under each corner and much better results would be obtained by that means. The load on the cork could be increased with advantage so long as it was not beyond its safe bearing capacity.

The President enquired what would cork take to the square inch?

Mr. Grey replied he had tested it up to 365 lb. to the sq. in. That compressed it from 2½ in. down to 1¼ in. Normally safe loading was about 10 to 12 lb. per sq. in.

With regard to flame roar, he had to confess that as far as the burner itself and the flame were concerned he did not know of any way of handling it. The boiler-shell generally took up the roar and transmitted it to the boiler seating. If the seatings were isolated part of the trouble was stopped and if in addition the room was isolated that would also help.

Mr. A. Fleming Browne then proposed a very hearty vote of thanks to Mr. Grey for his very interesting paper and lantern slides, and also for the trouble he had taken in bringing the various instruments for sound recording which were to be seen on the platform. He expressed his disappointment at the small number attending that night as the subject was of very great importance to heating and ventilating engineers.

Mr. Grey might be somewhat consoled by the fact that the paper would be published in the *Journal* of the Institution, when he was sure it would be widely read and appreciated.

The vote of thanks was carried by acclamation and Mr. Grey responded.

The President said as it was the last meeting of the Session he would like to take the opportunity of asking the members to pass a very hearty vote of thanks to Mr. L. A. Forni for the way he had managed the lantern during the session. It was of very great value to the Institution to have a lanternist like Mr. Forni; and he did not know where the gentleman who read papers with lantern slides would be without him.

The vote of thanks was carried by acclamation.

Mr. Forni, in acknowledging the vote, said he had always endeavoured to do everything he could, and the members had been very kind to him at all times in giving him every assistance. He was very glad to give his services at any time.

The meeting then terminated.

ALIGNMENT CHARTS, THEIR CONSTRUCTION AND USE

By A. C. PALLOT,
B.Sc.(Eng.), M.I.E.E., A.M.I.C.E., A.M.I.Mech.E. (Member)

ASSOCIATE MEMBERS AND GRADUATES SECTION

LONDON, JANUARY 15th, 1934

The number of formulæ, both rational and empirical, used in engineering is very large, but the great majority are capable of being reduced to the form of " nomograms " or alignment charts, the use of which greatly facilitates calculations of all kinds.

In its simplest form, an alignment chart consists of three vertical scales, each graduated in terms of one of three related variables, and so arranged that a straight-edge placed across the scales at any values of two of the variables will intersect the other scale at the corresponding value of the remaining variable.

Fig. 1 shows an elementary example of an alignment chart representing the equation $a + b = c$. A straight line joining any two values on the a and b scales will intersect the c scale at the sum of these values.

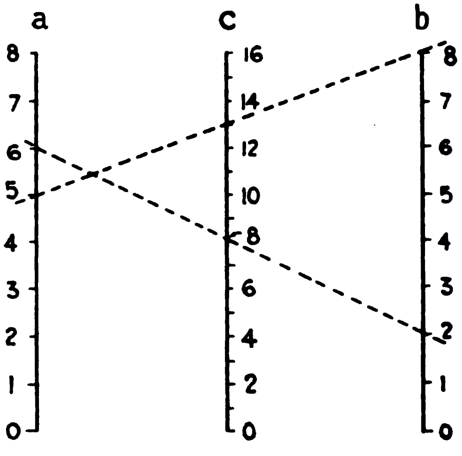


FIG. 1.—NOMOGRAM OF $a + b = c$

It is important to note that with parallel scales, one scale may be moved vertically relative to another, provided that the third scale is also moved by a proportionate amount. Thus Fig. 1 could be varied as shown in Fig. 2.

As the scales are equidistant in this case the c scale is depressed by one half of the amount by which the *b* scale is depressed, relative to the *a* scale.

The factors involved in the construction of alignment charts are therefore the finding of suitable horizontal spacings of the scales, and the graduations of the scales in relation to such spacings. This is effected by the application of some of the simpler properties of the algebraic symbol known as the "determinant."

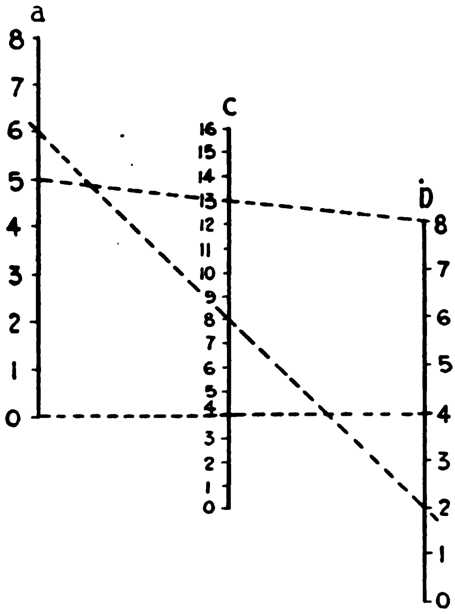


FIG. 2.—NOMOGRAM OF $a + b = c$.

A determinant is an expression of the form

$$\begin{vmatrix} x_1 & y_1 \\ x_2 & y_2 \end{vmatrix}$$

which represents $x_1 y_2 - y_1 x_2$

Similarly if

$$\begin{vmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix} = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

then

$$x_1 \begin{vmatrix} y_2 & 1 \\ y_3 & 1 \end{vmatrix} - y_1 \begin{vmatrix} x_2 & 1 \\ x_3 & 1 \end{vmatrix} + 1 \begin{vmatrix} x_2 & y_2 \\ x_3 & y_3 \end{vmatrix} = 0$$

whence $x_1 y_2 - x_1 y_3 - x_2 y_1 + x_3 y_1 + x_2 y_3 - x_3 y_2 = 0$

$$\text{or} \quad \frac{y_3 - y_1}{x_3 - x_1} = \frac{y_2 - y_1}{x_2 - x_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

This last equation implies that the points (x_1y_1) (x_2y_2) and (x_3y_3) are all in the same straight line. Determinant (1) must therefore have the same property, and thus if an equation can be expressed in the form of a determinant with unity in the last column, the variables y_1, y_2 and y_3 may be represented on vertical scales drawn with abscissæ of x_1, x_2 and x_3 respectively, and a straight line cutting the scales will show the related values of y_1, y_2 and y_3 at the points of intersection. If we make $x_1 = 1$, $x_2 = -1$, and $x_3 = 0$, equation (2) becomes

$$\frac{y_3 - y_1}{-1} = \frac{y_2 - y_1}{-2}$$

whence $y_1 + y_2 - 2y_3 = 0$ . . . . (3)

and the determinant (1) becomes

$$\begin{vmatrix} 1 & y_1 & 1 \\ -1 & y_2 & 1 \\ 0 & y_3 & 1 \end{vmatrix} = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

If equation (3) is written in the form

$$y_1 + y_2 + y_3 = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

the corresponding determinant becomes

$$\begin{vmatrix} 1 & y_1 & 1 \\ -1 & y_2 & 1 \\ 0 & \frac{-y_3}{2} & 1 \end{vmatrix} = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

The relationship between equation (5) and determinant (6) forms the basis of alignment chart construction, as if vertical axes for y_1 and y_2 are drawn at unit distance on either side of the vertical axis for y_3, the latter can be graduated to a scale of one half of that used for the other two, and any straight line across the three axes will satisfy equation (5). (Fig. 1 is a representation of this.) As an example, consider an alignment chart for the equation $ab = c$.

This may be put into standard form by writing it log. a + log. b - log. c = 0, and the resultant determinant is

$$\begin{vmatrix} 1 & y_1 = \log.\ a & 1 \\ -1 & y_2 = \log.\ b & 1 \\ 0 & \frac{-y_3}{2} = -\frac{1}{2}(-\log.\ c) & 1 \end{vmatrix} = 0$$

This relationship is represented in Fig. 3, in which the outer scales for a and b are graduated in terms of the logs. of the integers, while the middle scale of c is graduated in terms of $\frac{1}{2}$ the log. values.

With many of the formulæ used in practice, if the vertical axes were equidistant some of the scales would be inconveniently large or small. For example, if the numerical range of a in the above example were from 0 to 15, and of b from 10 to 100, it is obvious that the lengths of the two scales would be disproportionate.

To overcome this difficulty, the standard determinant is modified to the following form :—

$$\begin{vmatrix} A_1 & B_1 y_1 & 1 \\ -A_2 & B_2 y_2 & 1 \\ 0 & -\dfrac{B_1 B_2 y_3}{B_1 + B_2} & 1 \end{vmatrix} = 0$$

where $A_1 B_2 = A_2 B_1$

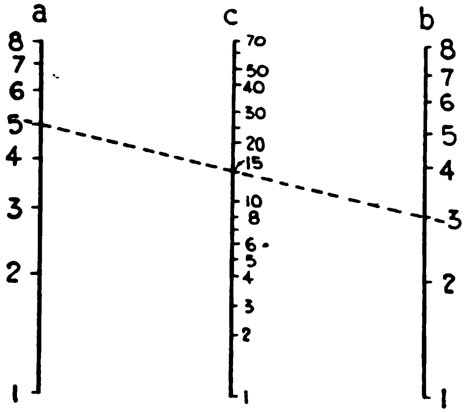


FIG. 3.—NOMOGRAM OF $ab = c$

This still expresses the equation $y_1 + y_2 + y_3 = 0$ and reduces to the form of determinant (6) when A_1, A_2, B_1 and B_2 all equal unity.

The values of B_1 and B_2 may be easily found. If r is the numerical range of any scale and q is the length which it is desired to make the scale, then

$$B = \frac{r}{q}$$

Thus if in the equation $ab = c$ the range of a is from 0 to 15, of b from 10 to 100, and the length of the a scale is to be 6 in., then $6 = B_1 \log. a = B_1 \times 1.176$

$$\therefore B_1 = 5.1$$

For the b scale, the numerical range is (log. 100 − log. 10) $= 2 - 1 = 1$, so that if the length is to be 6 in. as before, $B_2 = 6$.

The coefficient of y_3 in the c scale is

$$-\frac{B_1\ B_2}{B_1 + B_2} = -\frac{5.1 \times 6}{5.1 + 6} = -\frac{30.6}{11.1} = -2.76$$

As regards the spacing of the scales, let A_1 be 2 in. Then, since $A_1\,B_2 = A_2\,B_1$, $A_2 = \dfrac{2 \times 6}{5.1} = 2.36$ in.

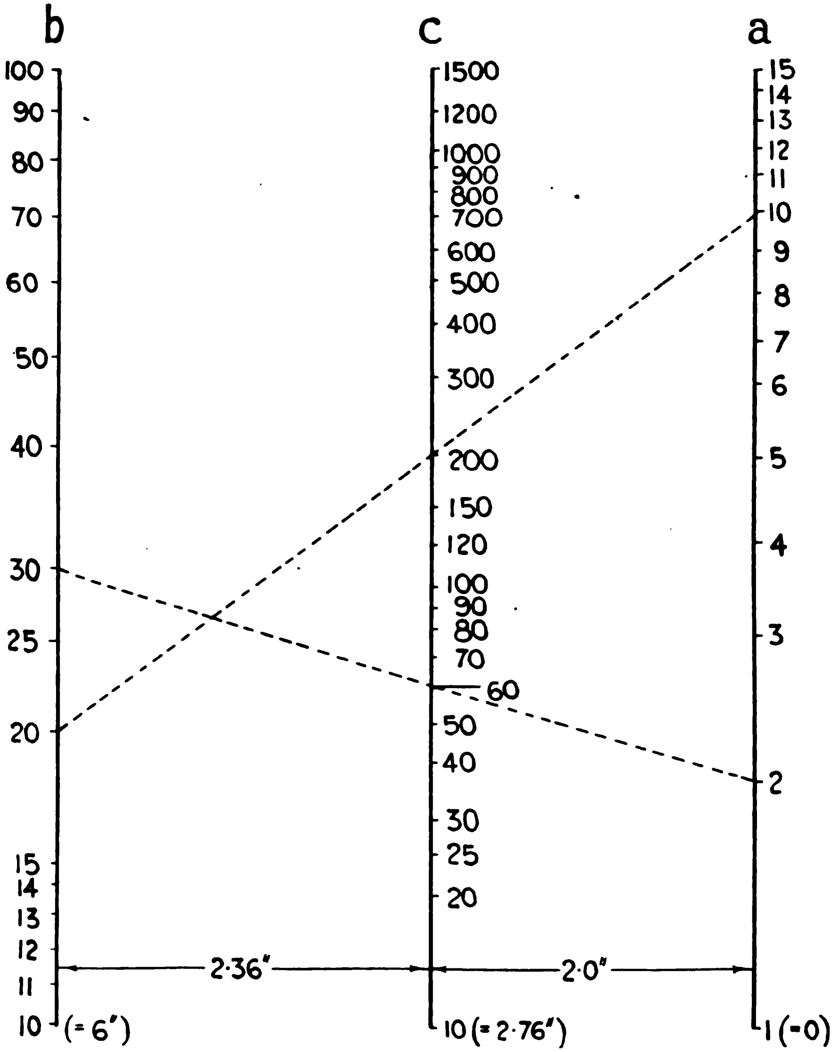


FIG. 4.—NOMOGRAM OF $ab = c$.

The determinant thus becomes

$$\begin{vmatrix} 2 & 5.1 \log. a & 1 \\ -2.36 & 6 \log. b & 1 \\ 0 & -2.76 (-\log. c) & 1 \end{vmatrix} = 0$$

The *a* scale is thus drawn 2 in. to the right of the *c* scale, and the *b* scale 2.36 in. to the left. Although the coefficient of log. *c* is negative, the numerical values will be positive, as the − ve sign is derived from the equation (5), in which y_3 is positive, whereas in the equation under consideration the sign of the y_3 term is negative.

The scales are graduated as follows. (A few typical calculations only are shown : obviously by taking a sufficient number of values, the graduations may be made as fine as desired.)

a	log. *a*	5.1 log. *a*	*b*	log. *b*	6 log. *b*	*c*	log. *c*	2.76 log. *c*
1	0	0	10	1.0	6.0	10	1.0	2.76
2	0.301	1.54	30	1.477	8.86	100	2.0	5.52
5	0.699	3.56	50	1.699	10.19	500	2.699	7.45
10	1.0	5.1	70	1.845	11.07	1000	3.0	8.27
15	1.176	6.0	100	2.0	12.0	1500	3.176	8.76

The length of each of the three scales is therefore 6 in., the *a* scale running from 0 to 6 in., and the *b* scale from 6 to 12 in. The initial reading on each of these two scales can be placed on the same horizontal datum line, and the position of the *c* scale can be determined by a single spot reading. Thus when $a = 1$ and $b = 10$, $c = 10$, and the corresponding lengths of the scales, measured from zero, cut by a horizontal line, are $a = 0$, $b = 6$, $c = 2.76$.

The complete nomogram is shown in Fig. 4. In practice there would be very little object in using a nomogram for such a simple expression as $ab = c$, as the results could be obtained without difficulty by means of a slide rule. The example has been included here solely as a simple illustration of method.

As a more practical example, consider a nomogram to enable the amount of heating surface to be readily ascertained for various conditions.

Assume that a rise in temperature of from 30° F. to 62° F. is required, and that hot-water heating will be used, with an emission of 160 B.T.U. per hour per sq. ft. of heating surface. Then

$S \times 160 = 32 \times kE$ where

s is the heating surface

E is the exposed area of wall, etc.

k is the coefficient of transmission for the particular material of wall, etc.

$$\therefore S = 0.2\, kE, \text{ or } \log. k + \log. (0.2E) - \log. S = 0.$$

The arrangement of the nomographic scales for the equation of $y_1 + y_2 + y_3 = 0$ is as follows :

y_1	y_2	y_3
right	left	centre

In the nomogram for heating surface, it is important that the graduations of the S scale should be fairly open, in order that the values of S may be read as accurately as possible. The k scale will be graduated at a comparatively few definite points, which may be grouped close together without loss of accuracy. It is therefore desirable that the k scale should be made central, so that the formula is written

$$-\log. S + \log. (0.2E) + \log. k = 0,$$

and the determinant becomes

$$\begin{vmatrix} A_1 & B_1\,(-\log. S) & 1 \\ -A_2 & B_2\,(\log. 0.2E) & 1 \\ 0 & -\dfrac{B_1\;B_2}{B_1+B_2}\log. k & 1 \end{vmatrix} = 0$$

Assume that k will have values of from 0.1 to 2.5, that E will have values of from 10 to 1,000 sq. ft., and that the maximum value of S will be 100 sq. ft.

The numerical value of the S scale will be log. 100, = 2, and of the E scale (log. 200 − log. 2) which also = 2, Thus if the lengths of the S and E scales are each to be 8 in., and the distance of either from the k scale is 3 in., the determinant becomes

$$\begin{vmatrix} 3 & 4\,(-\log. S) & 1 \\ -3 & 4\,(\log. 0.2E) & 1 \\ 0 & -2\log. k & 1 \end{vmatrix} = 0$$

Typical graduations of the S and E scales are as follows :

E	$0.2E$	log. $0.2E$	4 log. $0.2E$	S	log. S	−4 log. S
10	2	0.301	1.2	1	0	0
50	10	1.0	4.0	5	0.699	−2.4
100	20	1.301	5.2	10	1.0	−4.0
500	100	2.0	8.0	50	1.699	−6.4
1000	200	2.301	9.2	100	2.0	−8

The scale of k for various materials is as follows :—

Material	k	log. k		−2 log. k
Wood blocks on 6 in. concrete ..	0.1	$\bar{1}.0$	= −1	2
18 in. brick wall (with cavity) ..	0.22	$\bar{1}.342$	= −0.658	1.31
13½ in. „ „ „ ..	0.25	$\bar{1}.398$	= −0.602	1.2
9 in. „ „ „ ..	0.29	$\bar{1}.462$	= −0.538	1.07
4½ in. brick wall	0.33	$\bar{1}.518$	= −0.482	0.96

Material	k	log. k		-2 log. k
Lath and plaster ceiling, boarded	0.4	$\bar{1}.602$	$= -0.398$	0.79
6 in. concrete	0.57	$\bar{1}.756$	$= -0.244$	0.49
Slates	0.82	$\bar{1}.914$	$= -0.086$	0.17
Glass window	1.0	0	0	
Glass skylight	1.5	0.176		-0.35
Corrugated asbestos	1.25	0.097		-0.19
Corrugated iron	2.17	0.336		-0.67

The range of the scales is therefore as follows :—

E scale : from 1.2 to 9.2 in.
S ,, : from 0 to -8 in.
k ,, : from -0.67 to 2 in.

In order to bring the three scales into line, the -8 in. graduation of the S scale can be brought opposite the 1.2 graduation of the E scale and both will then extend upwards for a distance of 8 in. This is equivalent to adding 9.2 to the S scale, and half this amount should therefore be added to the k scale, the initial reading ($= 0.67$ in.) of which will then be $(4.6 - 0.67 - 1.2) = 2.73$ in. above the initial readings of the S and E scales.

(Alternatively the final position of the k scale could be found by trial : it is only necessary to fix one point in relation to the E and S scales.)

As regards the heating surface required for the air changes, if C is the cubic content and n the number of air changes per hour, we have, for the same temperature conditions as before,

$$160\,S = 0.02 \times 32\,nC$$
$$\therefore \quad S = 0.004\,nC$$

S per 1,000 cu. ft. for various values of n is then as follows :—

$n =$	0.5	1	1.5	2	3	4
$S =$	2	4	6	8	12	16

These values can be added to the chart by drawing lines through the 1,000 graduation of the E scale, and the various values of S, as found, on the S scale. The points of intersection on the k scale can then be marked in terms of n. The E scale can be used as a volume scale and the value of S for any values of E and n can be found. The final nomogram is shown in Fig. 5.

Formulæ involving more than three variables can be reduced to nomographic form by the introduction of an auxiliary scale, which need not be graduated. As an example, consider the formula for the loss of head by friction in a pipe conveying water.

This is $H = 4f\,\dfrac{L}{d}\,\dfrac{v^2}{2g}$ (H is loss in feet)

If L is in feet, d in inches, and v in feet per second, this becomes

$$H = 0.0056\ L\ \frac{v^2}{d}$$

The rate of flow G in gallons per minute is very nearly $2d^2v$, so that

$$H = 0.0014\ L\ G^2\ d^{-5}$$

Thus $\log.\ (0.0014\ L) + 2\ \log.\ G - 5\ \log.\ d - \log.\ H = 0$

This may be written

$$\log.\ K - \log.\ (0.0014\ L) - 2\ \log.\ G = 0$$

where $\log.\ K - 5\ \log.\ d - \log.\ H = 0$

Separate determinants may be found for this pair of equations: these are linked by the common term log. K, which merely represents a scale of reference, and need not be evaluated.

The terms of the two equations can be taken in any order so as to give the most convenient arrangement of the scales of the nomogram. In this case it will be advantageous to make the order of the scales for the first equation G, K, L, and for the second equation K, d, H. The equations are therefore written

$$\log.\ 0.0014\ L + 2\ \log.\ G - \log.\ K = 0 \quad \ldots\ldots\ldots\ldots \text{I}$$

$$\text{and} - \log.\ H + \log.\ K - 5\ \log.\ d = 0 \quad \ldots\ldots\ldots \text{II}$$

Assume that the quantities will have the following limits :—

L : from 10 ft. to 100 ft.
G : from 1 to 500 gallons per minute.
d : from 1 to 6 in.
H : from 0.1 to 10 ft.

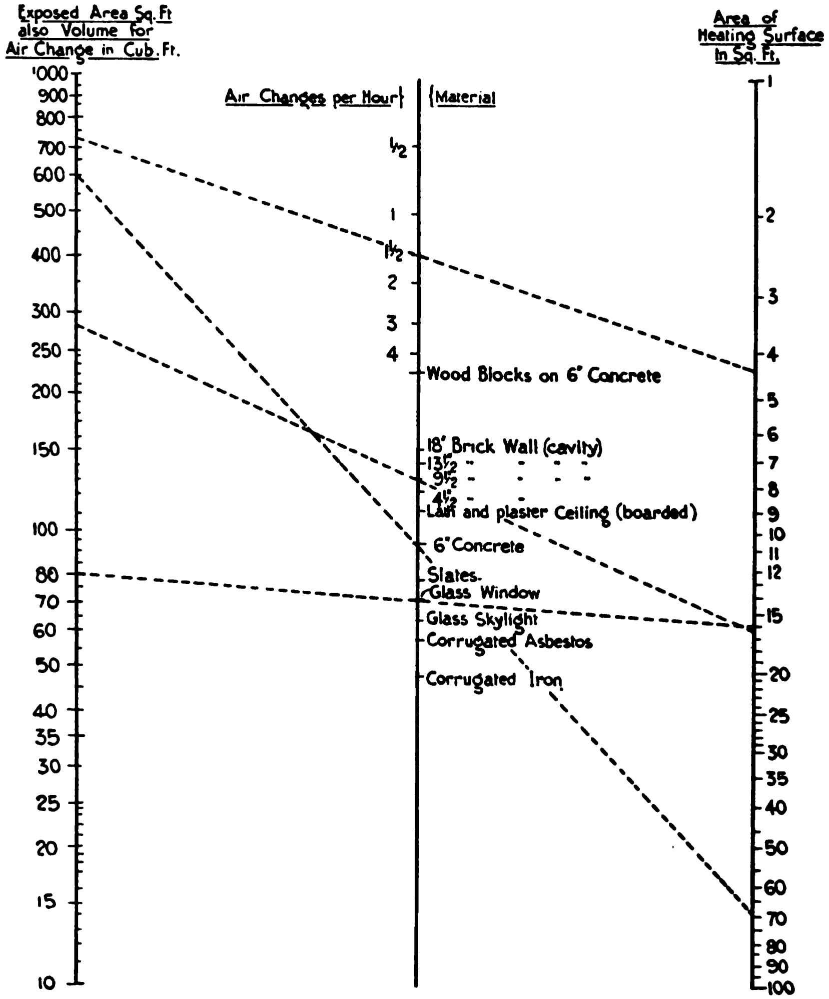
(Note : losses of head of more than 10 ft. per 100 ft. length of pipe are very unusual, and for heating and similar systems are always much less.)

The numerical values of the various terms are then :—

L : $\log.\ 0.014$ to $\log.\ 0.14 = 1$
G : $2\ \log.\ 1$ to $2\ \log.\ 500 = 2 \times 2.7 = 5.4$
d : $5\ \log.\ 1$ to $5\ \log.\ 6 = 5 \times 0.778 = 3.89$
H : from $\log.\ 0.1$ to $\log.\ 10 = 2$

For equation (1) the determinant is

$$\begin{vmatrix} A_1 & B_1 \log.\ 0.0014\ L & 1 \\ -A_2 & B_2 \times 2\ \log.\ G & 1 \\ 0 & -\dfrac{B_1\ B_2}{B_1 + B_2}\ (-\log.\ K) & 1 \end{vmatrix} = 0$$



Example:– Room 30' long × 20' wide × 12' high, outer wall (exposed) 9½ brick with cavity, roof (exposed) 6" concrete, 4 windows in wall each 5'×4'.

Area of wall = 30×12 = 360 sq. ft
" " glass = 4×(5×4) = 80 " " s = 16
" " brick = 280 " " s = 16½
" " roof = 30×20 = 600 " " s = 70
Total s for exposure = 102½
Vol. of Room = 7,200 cub ft. Air Changes 1·5
s per 720 cub. ft. = 4·4 ∴ s for Room = 44
Total Heating Surface = 146½

FIG. 5.—NOMOGRAM FOR HOT-WATER HEATING SURFACE

Lengths of scales :

$$L = 6 \text{ in.} \quad \therefore \quad B_1 = 6$$

$$G = 6 \text{ in.} \quad \therefore \quad B_2 = \frac{6}{5.4} = 1.11$$

$$\frac{B_1 \; B_2}{B_1 + B_2} = \frac{6 \times 1.11}{6 + 1.11} = \frac{6.66}{7.11} = 0.94$$

$$\text{If } A_1 = 3 \text{ in.}, A_2 = \frac{A_1 B_2}{B_1} = \frac{3 \times 1.11}{6} = 0.55 \text{ in.}$$

The determinant becomes

$$\begin{vmatrix} 3 & 6 \log. 0.0014\, L & 1 \\ -0.55 & 2.22 \log. G & 1 \\ 0 & 0.94 \log. K & 1 \end{vmatrix} = 0$$

Typical scale values are :

L	6 log. 0.0014 L	G	2.22 log. G
10	-11.12	1	0
25	- 8.73	10	2.22
50	- 6.93	100	4.44
75	- 5.87	250	5.32
100	- 5.12	500	6.0

For equation (2) the determinant is :

$$\begin{vmatrix} A_1 & B_1 (-\log. H) & 1 \\ -A_2 & B_2 \log. K & 1 \\ 0 & -\dfrac{B_1 \; B_2}{B_1 + B_2} (-5 \log. d) & 1 \end{vmatrix} = 0$$

Lengths of scales :

$$H = 6 \text{ in.} \quad \therefore \quad B_1 = \frac{6}{2} = 3$$

$B_2 = 0.94$, as the K term must be identical with that in the determinant for G and L : lines drawn through co-related values of G and L, and d and H, will then intersect on the K scale.

$$\frac{B_1 \; B_2}{B_1 + B_2} = \frac{3 \times 0.94}{3 + 0.94} = \frac{2.82}{3.94} = 0.715$$

$$\text{If } A_2 = 1.25, A_1 = \frac{A_2 B_1}{B_2} = \frac{1.25 \times 3}{0.94} = 4 \text{ in.}$$

The determinant becomes

$$\begin{vmatrix} 4 & -3 \log. H & 1 \\ -1.25 & 0.94 \log. K & 1 \\ 0 & 3.575 \log. d & 1 \end{vmatrix} = 0$$

Typical scale values are :

H	$-3 \log. H$	d	$3.575 \log. d$
0.1	3	1	0
1	0	2	1.07
5	−2.1	3	1.71
8.5	−2.79	4	2.14
10	−3	6	2.78

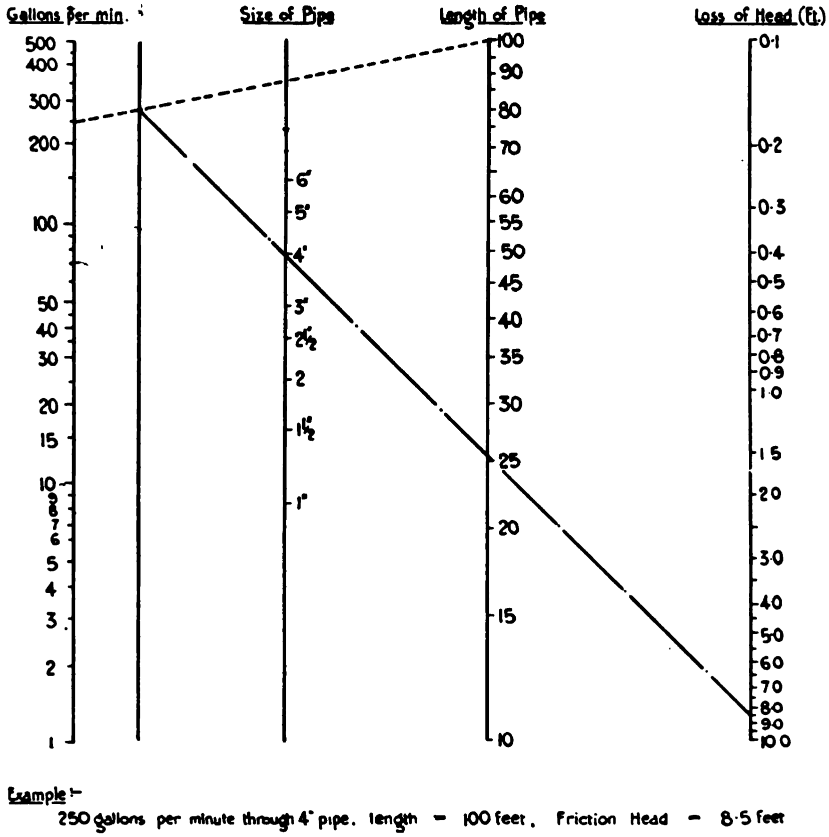


FIG. 6.—NOMOGRAM FOR FRICTION HEAD IN PIPES

The ranges of the various scales, as found, are therefore as follows :

L from −11.12 in. to −5.12 in.
G „ 0 „ 6 in.
H „ 3 „ −3 in.
d „ 0 „ 2.78 in.

A nomogram in this form would obviously be inconvenient in use, but the scales may very easily be brought more nearly into alignment. To do this, it is only necessary to draw any three of them in any required position, the correct horizontal spacings being of course maintained. Then if the value of H for any values of G, L, and d be found from the original formula, a line can be drawn through these values of G and L on the appropriate scales. A line joining the intersection of this line and the K scale with the value of H will cut the d scale at the corresponding value of d and this fixes the position of the d scale. Thus if $G = 250$ gallons, $L = 100$ ft. and $d = 4$ in.,

$$H = \frac{0.0014\ L\ G^2}{d^5} = 8.5 \text{ ft.}$$

The nomogram is shown in Fig. 6. The G, L and H scales are drawn with their initial readings on the same horizontal line. A line joining 250 on the G scale and 100 on the L scale will intersect the K scale as shown, and a second line joining this point with 8.5 on the H scale will intersect the d scale at the point where $d = 4$ in. The d scale can then be graduated.

In a practical case, the quantities usually fixed by the conditions of the problem are G and L. (L may include not only the straight lengths of pipe, but the " equivalent lengths " allowed for the resistance of bends, valves and other features.) The friction head corresponding to any value of d can then be found from the chart. As a simple example, take the case of a circulation 400 ft. in length requiring a flow of 30 gallons per minute. The equivalent lengths of the fittings, according to published tables, are

	2 in. pipe	2½ in. pipe	3 in. pipe
Boiler	24	28.5	36
10 long-sweep bends	25	30	40
2 gate valves (half open)	32	38	48
Totals	81	96.5	124
Total equivalent lengths	481 ft.	496.5 ft.	524 ft.

These lengths are greater than the scale of the chart, but the friction loss for one-tenth of each length can be obtained from the chart, and this multiplied by 10 will give the total. The results thus found are as follows :

Size of pipe	2 in	2½ in.	3 in.
Friction head	20 ft.	7.5 ft.	3 ft.

Thus a suitable pump can be chosen for use with the selected size of pipe.

Formulæ containing more than four variables can be expressed in nomographic form by the introduction of two or more auxiliary scales, the procedure being exactly as before.

Nomograms are not so suitable as curves for showing the form of the relationship between variables, *e.g.*, they do not show at a glance the rates of variation, and are thus not ideal for the presentation of data. For use in calculations, however, they have great advantages over curves, particularly in so far as they show by a few lines the information which would otherwise require a large number of separate curves.

Nomograms with straight parallel scales form only one group of alignment charts, as some expressions are better dealt with by making use of curved scales, but a little ingenuity enables most of the formulæ in common use to be dealt with by the methods indicated.

BUILDING RESEARCH STATION, GARSTON, NR. WATFORD, HERTS.

DEGREE-DAYS

By A. F. DUFTON, M.A., D.I.C.

ALTHOUGH it is well known that more fuel is required to heat a house in the north of our island than in the south, few people have an accurate idea of how fuel consumption varies with locality. The data upon which such an idea can be based, however, are available in the form of monthly normals of temperature (max., min. and mean) in Section I of "The Book of Normals," published by the Meteorological Office (H.M.S.O., 2s. net).

American engineers have taken considerable interest in fuel consumption and have found the "degree-day" to be a very useful unit of reference. The term degree-day originated in the gas industry and was standardised by the American Gas Association as a unit which is the difference between 65° F. and the daily mean temperature when the latter is below 65° F. Unless otherwise specified, the number of degree-days for a locality is always taken to mean the annual total.

In America, the base of 65° F. was chosen (for inside temperatures of 70° F.) because it was demonstrated that 65° F. usually is the maximum temperature at which fuel is burned to supply heat to a residence and because the fuel consumed varied almost directly with the difference between 65° F. and the outside temperature.[1]

---

[1] *A.S.H.V.E. Guide* 1933, p. 277.

In our own country, where an inside temperature of 65° F. is generally preferred to one of 70° F., it would seem desirable to adopt a temperature of 60° F. as the base for a British degree-day.

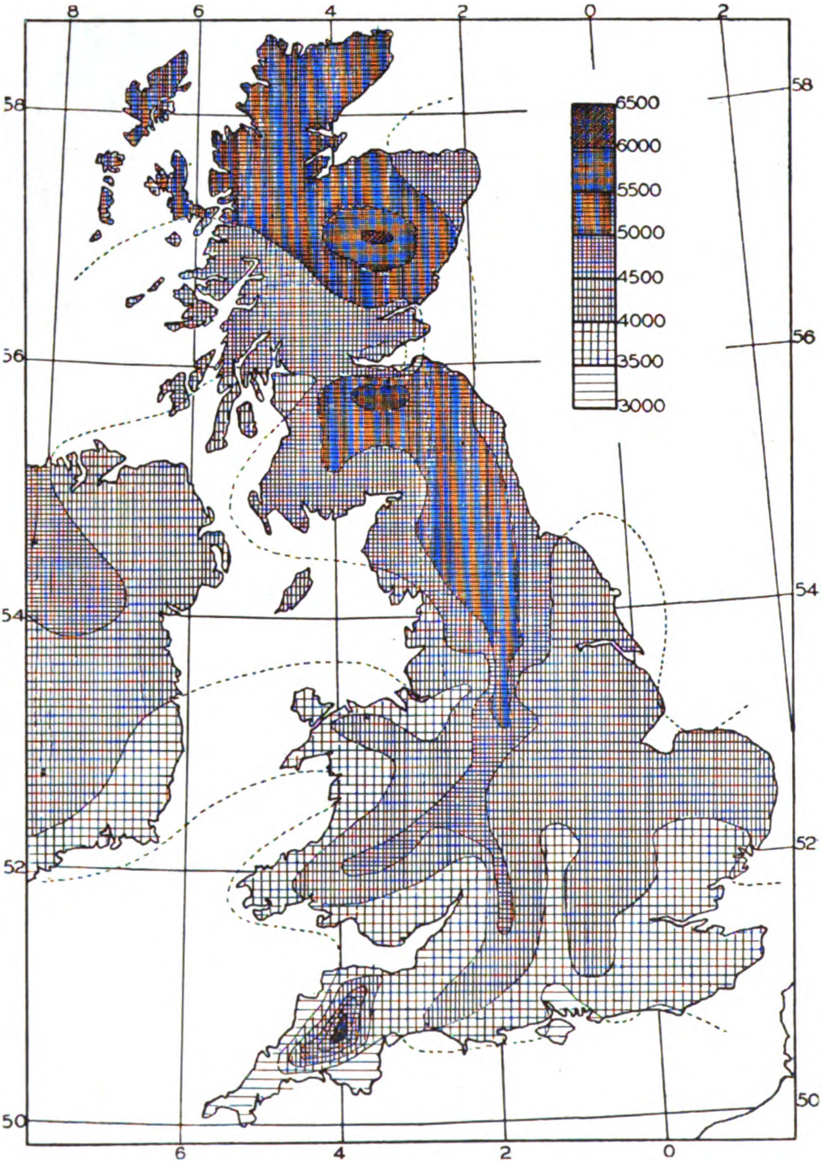


Fig. 1.—British Degree-Days.

Reference to " The Book of Normals " indicates that, at Greenwich, on this basis, heating is normally unnecessary from about the middle of June to the end of the first week in September ; and this seems to be reasonable.

The accompanying map (Fig. 1) which shows British degree-days for Great Britain and Northern Ireland, is contoured from the information given in " The Book of Normals."

In the interests of accuracy, it must be pointed out that only two of the stations for which data are given are more than 1,000 ft. above mean sea level—Braemar (1,120 ft.) and Princetown (1,359 ft.)—and it will be seen that, while Dartmoor appears as a cold spot, the contouring does not truly show the coldness of Snowdon or of Ben Nevis. The effect of altitude, which amounts to an increase of roughly one degree-day per foot, is complicated by the influence of the configuration of the land and of the distance from the sea. It has not been thought worth while to attempt to amend the contouring by adopting such a correction, particularly as the areas remote from meteorological stations are all sparsely populated.

It is of interest that Mr. A. H. Barker, in his comprehensive paper on " The Relative Fuel Economy of Electricity, Gas, Oil and Solid Fuel as Heating Agents,"[2] calculated the total fuel used throughout a winter as equivalent to 20 weeks at full power, full power being that required to maintain an internal temperature of 60° F. with an external temperature of 30° F. These figures imply a total of 4,200 degree-days and the map confirms that this is a good average figure for England.

NEW BOOKS

HEAT TRANSFER*

THIS translation of Schack's celebrated " Der Industrielle Wärmeübergang " should prove invaluable to all who, whilst wishing to keep in touch with fundamental work in heat transfer, have found the reading of a highly specialised technical subject in a foreign language a serious obstacle. As the translators remark " Conversion from one language to another is a difficult matter at best, since shades of meaning may be quite lost in a liberal translation, while ideas may be misinterpreted in a more general treatment." The latter fault is the more serious in a technical treatise, and so far as can be judged from a careful but necessarily incomplete comparison of the translation with the original, the translators have avoided it successfully, whilst by including reference to a number of American papers published since 1929 and distinguishing the more important equations by an asterisk they have materially added to the value of the book. They are careful, however, to disclaim any intention of rewriting Schack's book and state that " the choice of data and the critical evaluation of these data is therefore almost entirely that of the author." The serious student of heat transfer can thus feel assured that he is getting the essence of Schack's ideas and can make his own comparison of these with other recent treatments of the subject such as those of McAdams in America or Fishenden and Saunders in this country.

---

[2] *Journal I.H.V.E.* 1933. Vol. 1, p. 344.

* " Industrial Heat Transfer." By Alfred Schack, translated from the German by Hans Goldschmidt and Everett P. Partridge. 6 in. by 9¼ in. xxii and 371 pages. 40 Illustrations. Cloth. New York : John Wiley & Sons ; London : Chapman & Hall Ltd., 1933. Price 31s. net.

It is difficult in the course of a review to indicate the contents of such a book : a mere list would alone fill all the space available for this notice. The main divisions analyse in great detail the mechanism of heat transfer by conduction, convection and radiation, including a lengthy treatment of variable heat flow. The author recognises that in some instances equations derived theoretically are not always readily applicable to practice and gives approximate solutions (*cf.* p. 54). English readers will probably find the account of non-luminous gas radiation (p. 182 *et seq.*) of outstanding interest in view of the author's pioneer work on this subject and may be slightly disappointed that the treatment is not fuller. The translators help here by a reference to the extremely interesting work of Hottel which should be consulted. The numerous practical examples give a satisfying solidity to a subject which is regarded in some quarters as of somewhat academic interest, whilst the usefulness of the tables of physical constants is enhanced by the citation of the authorities for the figures quoted.

English readers should note that the symbols, etc., used conform to the recommendations of the American Standards Association wherever possible, and should observe, for example, the differences between American and English practice in pipe sizes (p. xviii). It is probable that some errors will have crept into the numerous conversions from the metric system of units to the English, but so far the reviewer has found none.

Altogether this is a work to be highly commended, especially to the members of this Institution, who will remember Mr. Lubbock's extremely interesting account of the application of some of Schack's ideas given at the Summer Meeting last year and be grateful for the opportunity of studying the subject more fully.

THOS. G. NOBLE.

STEAM HEATING

The practice of heating has made considerable advances during the last decade and many new ideas in theory and practice have been introduced, consequently it is rather disappointing to find that the new edition of Mr. Dye's book* has not been revised to conform with the progress made since 1922. Mr. Dye has long been recognised as the producer of elementary books on heating and hot-water supply and this book has been written in the same simple manner which will make its appeal to the beginner. In its fifteen chapters he deals with the principles of steam heat, ordinary heating systems, temperature calculations for radiation, warming by overhead pipes, sundry information, heating water by steam and cooking by steam. Three other chapters are on heating by exhaust steam, vapour and vacuum systems and the unit system of steam heating. These latter chapters show the necessity for revision and expansion as only the early systems are dealt with. Since the original edition new systems and methods, for these types of steam heating, have been introduced and have secured many adherents and produced many successful installations. The steam tables still appear without any knowledge of the authority and in the tables of properties of steam the author still fails to mention that the figures given for the heat units in a pound of water and per pound of steam are above 0° F. and not above 32° F., which is the usual basis of modern steam tables, such as those of Callendar. In discussing steam from high-pressure boilers the statement that radiators are tested by the makers to 50 lb. per sq. in. is still uncorrected, although catalogues state that they are tested to 100 lb. per sq. in., which is the same as that for the special form of radiator described. Descriptions are given of one-pipe and two-pipe systems with tables for pipe sizing, but such tables are obviously out of date, the sizes being given for square feet of radiation instead of B.T.U. and again in the chapter dealing with calculations the coefficients for heat emission from radiators are not applicable to modern types. Consequently the square feet table for pipe sizing is very misleading. This criticism applies also to the table for finding the area of low-pressure steam radiation required for brick-built rooms per 1,000 cu. ft. of space. The book, however, will be found of value to the student who wishes to obtain an elementary knowledge of the subject, as it contains useful and practical information without going into the theoretical and mathematical side of the work.

---

* "Steam Heating." By Fredk. W. Dye. 5 in. by 7½ in. 203 pages, 57 illustrations. Cloth. Published by E. & F. N. Spon Ltd., London, 1934. Price 7s. 6d. net.

VENTILATION

THE people of this country are becoming increasingly interested in the air they breathe and consequently when they visit a theatre, cinema or public hall they demand comfort conditions in which to enjoy their entertainment. The effect of this desire has been responsible for the increasing development of ventilation in this country. Mr. E. L. Joselin, as a lecturer in heating and ventilation, has found the necessity for a text-book based on British practice, as it is difficult to recommend students to books, based on American requirements, which may not be in accordance with the information delivered in his lectures. This book* has been arranged on a well-thought-out plan and opens with a chapter on atmospheric air, the estimation of its constituents, measuring instruments, the basic laws of gases and humidity with an explanation of the use of the psychrometric chart. The standards of ventilation, in a fluid state in this country, are described in chapter 2, so that American recommendations are considered in relation to British ideas. The theory and practice of natural ventilation are found in Chapter 3, as it is still used in this country, though as the author suggests, it could be made more effective if closer attention were given to the principles involved. The next three chapters give brief information on mechanical ventilation systems, the theory of the flow of air through ducts (including a folded chart) and the method of designing air ducts with examples based on the " velocity" and " pressure drop " systems. Duct construction is briefly dealt with. It is natural, perhaps, that we should find that the author, who has had more than 20 years' experience in the design of fans and their industrial application, has given the most attention to fan construction, operation, testing and use, in the two longest chapters. The information on graphs in relation to fans will be found of real value. The author has made good use of the Institution's Fan Standardisation Report. Chapter 9, on ventilation combined with heating, is devoted principally to types of air heaters and calculations. Chapter 10, on air purification, is mainly descriptions of apparatus. Chapter 11, on air-conditioning, is the most interesting chapter in that it not only describes the Carrier psychrometric chart, but includes the author's own chart, prepared from English data, with detailed examples of its use. The final chapter deals with recent developments. The book is intended principally for the student, draughtsman, the engineer and the architect and as a text-book it will be heartily welcomed owing to the dearth of reliable books on this subject produced in this country.

---

* "Ventilation. A Text-book for Students and Engineers." By E. L. Joselin. 9¼ in. by 6 in. 238 pages, 165 illustrations and 2 folded charts. Cloth. Published by Edward Arnold & Co., London, 1934. Price 16s. net.

ABSTRACTS

Ripening Bananas. 634

Naturally the principal factors entering into the actual process of ripening are temperature, humidity and ventilation. The preferred temperature range varies from 62 to 68° F., though ten degrees higher is often given to hard, green fruit for a half-day period without injurious result. Generally, though, for turning or ripe fruit, the temperature is usually kept around 66° F. If rapid ripening is necessary then the temperature may be increased as much as three degrees every hour until such time as the desired stage of ripeness has been achieved. A high humidity has been found desirable to obviate excessive shrinking, and this is especially true in instances where air velocity is high from forced air circulation, as it prevents a drying out of the fruit, but as soon as the fruit commences to colour the humidity is reduced to around 70 per cent. to avoid it becoming mouldy or soft. Shrinking usually varies from 2 to 3.8 per cent., depending upon the relative humidity. The carbon dioxide and volatile esters exuded by the bananas during the process of ripening are confined in the room as they appear to have the advantage of aiding the fruit to ripen more readily than if they were expelled by ventilation. Some ventilation has to be given where heating is by gas burners, but otherwise no ventilation is given the fruit in the ripening room until it starts to colour, at which time ventilation serves to reduce humidity as well as freshening the air in the rooms. (C. F. Greeves-Carpenter, *Refrigerating Engineering*, February 1934.)

Belts and Ropes. 621.852

Progress has been mainly in the direction of new types of belting for conditions for which the original belting is unsuitable. The materials in general use for belting include leather, balata, rubber and woven hair, and for some purposes combinations of these materials. The balata and rubber belts are composed of cotton duck impregnated with balata or rubber to give the requisite adhesion and protection to the strands. Leather has a comparatively high coefficient of friction, but a balata belt is stronger for a given thickness. For a heavy drive a combination of leather and balata may be used advantageously, the former in contact with the pulley to obtain a good frictional grip, and the latter outside to provide the necessary strength. For heavy drives around small pulleys a thick leather belt would suffer from the repeated bending. A good solution is provided by the use of a balata belt fitted with narrow transverse strips of leather on its inner surface. The spaces between the leather strips permit full contact between the leather and the pulley without setting up bending stresses, while the comparatively thin balata belt is not unduly affected by the bending action. Leather is not suitable for drives exposed to heat, moisture or acids. Balata resists steamy or moist atmospheres, and woven hair is suitable for conditions in which the belt is exposed to moisture, oil, or dilute acids.

In rope driving, cotton is the material in general use for twisted ropes, the cotton giving better service than hemp, owing to its better flexibility and resistance to repeated bending. An alternative construction is the square rope, consisting of eight strands plaited together. In this type the action between the strands is of a sliding rather than a bending nature, and for this reason hemp gives better results than cotton. The V-belt has been adopted for many driving purposes for which ropes were originally used. The belt is shaped to fit the inclined sides of the groove of the ordinary rope pulley, and the frictional contact is distributed over a greater area, giving better distribution of the load and less distortion and wear of the belt. (E. Griffen. *The Steam Engineer*, February 1934.)

Refrigeration for Air Conditioning. 621.56.

When the refrigerating cycle of evaporation and liquefaction is used, it is necessary for the boiling point of a refrigerant to be below the temperature to which the substance to be cooled is to be lowered. This is done by modifying the pressure to which a refrigerant is subjected in the evaporator, the latter being surrounded by a substance to be cooled, such as water in the majority of air-conditioning installations, by brine in some cases, and by flowing air when air is cooled directly by coils within which the refrigerant is vaporised.

Refrigerants with high boiling points at normal atmospheric pressure—namely, carrene, dielene and ethyl chloride—must be evaporated at pressures below atmosphere so as to reduce their boiling points to approximately 30 to 37° F. These evaporation temperatures are usually the requirements in air conditioning for comfort for all refrigerants and have the advantage of preventing ice formation on cooling coils covered with flowing water under normal operating conditions.

For cold-storage work or requirements of low temperature air-conditioning work, naturally lower refrigerant boiling temperatures must be used, which shows that refrigerants as mentioned above have limited application in low-temperature work.

Refrigerants with low boiling points at atmospheric pressure—namely, carbon dioxide, ammonia, F-12, methyl chloride and sulphur dioxide—must be evaporated at pressures above atmosphere in order to raise their boiling points to around 30 to 37° F. for comfort cooling requirement. (W. R. Rhoton. *Bull. Heating, Piping and Air Conditioning Contractors Nat. Assoc.* February 1934.)

HEATING AND VENTILATING INDEX

CO_2 Recorder. 621.171

A Boiler House Orsat Set. Karl Münzer. 2 pp., 3 illus. Description of gas analyser and method of using : *Engineering Progress*, January 1934.

Welding. 621.73

Bronze Welding of Cracked Cast-Iron Boiler Sections. 2 pp., 7 illus. Dealing with preparation of section, welding operation, preheating and summary : *The Sanitary Age*, January 12th, 1934.

Heat Losses. 536.2

Heat Losses. Leslie Rayner. 3 pp. Dealing with heat losses and describing quick methods of approximation : *The Plumber*, February 1st, 1934.

Domestic Hot Water. 696

Hot Water Supplies. W. E. Fretwell. 2½ pp., 1 illus. Dealing with measurement of heat, heat transmission and piping : *The Plumber*, February 1st, 1934.

Non-conducting Covering. 621.185.6

Isolation des Tuyaux. B. Guillot. 2 pp. Discussing loss of heat from piping and economy obtained by using non-conducting covering : *La Couverture-Plomberie*, January 1934.

Hot-Water Heating. 697.4

Etude de la circulation dans le chauffage par l'eau chaude. J. Quint. 5 pp., 3 illus. Study of circulation in hot-water heating and heat emission from radiators : *Chauffage-Ventilation*, January 1934.

Non-conducting Covering. 621.185.6

De l'influence des pertes calorifiques dans les services d'eau chaude. M. Hottinger. 7¼ pp. Dealing with covering of cylinders and pipes, influence of heat losses, efficiency and costs : *Chauffage-Ventilation*, January 1934.

Radiators. 697

Convector Heaters Available in Many Forms, Materials and Sizes. 7 pp., 10 illus. Study of 31 convectors, material, enclosures and control : *Heating and Ventilating*, February 1934.

Registers. 697.9

Design and Location of Registers and Grilles. Walter J. Ottinger. 2½ pp., 4 illus. Dealing with resistance, controls and sizing : *Heating and Ventilating*, February 1934.

Electric Motors. 621.3

Small Motors for Air Conditioning Plants. L. Gwathmey and B. S. Weaver. 2¾ pp., 5 illus. Dealing with general considerations, types of motors available : *Heating and Ventilating*, February 1934.

Automatic Control. 697

Typical Appliances for Automatic Heating. T. N. Thomson. 3½ pp., 7 illus. Dealing with pressure, volume, draught, combustion, air and temperature controls : *Plumbing and Heating Trade Journal*, February 1934.

Electric Motors. 621.3

Electricity Facts. R. C. Allen. 5 pp., 9 illus. Dealing with power, efficiency and revolutions and types of motors : *Domestic Engineering*, February 1934.

Exhaust Steam. 621.185

Exhaust Steam Utilisation offers Economy to Plants and Buildings. Perry West. 6 pp., 7 illus. Dealing with exhaust steam, back pressures, uses for exhaust steam and study of heating loads and exhaust supply by means of curves : *Heating, Piping and Air Conditioning*, February 1934.

Solar Radiation. 523.72

Studies of Solar Radiation through Bare and Shaded Windows. F. C. Houghten, Carl Gutberlet and J. L. Blackshaw. 8 pp., 6 illus. Investigation of heat gain through windows under different weather conditions : *Heating, Piping and Air Conditioning*, February 1934.

Cooling. 697.96

Comfort Cooling with Attic Ventilating Fans. G. B. Helmrich and G. H. Tuttle. 4½ pp., 8 illus. Describing experiments and features of design and construction : *Heating, Piping and Air Conditioning*, February 1934.

Coal Analysis. 543.6

The Meaning of Coal Analysis. Clarence A. Seyler. 3 pp., 1 illus. Explaining method of obtaining chemical analysis and chief characters and uses of different classes of coal : *The Fuel Economist*, February 1934.

Refrigeration. 621.56

Air Conditioning for Heating Contractors. W. R. Rhoton. 5½ pp., 1 illus. Dealing with mechanical refrigeration, its application and practice : *Bull. Heating, Piping and Air Conditioning Contractors Nat. Assoc.*, February 1934.

THE COMPUTATION OF HEAT LOSS COEFFICIENTS

By R. A. PRICE (Associate Member)

ASSOCIATE MEMBERS AND GRADUATES SECTION

LIVERPOOL, JANUARY 10th, 1934

Introduction.

I am privileged this evening to read to you a paper on the computation of heat loss coefficients, a title impulsively submitted upon the invitation of our Chairman. It is with some measure of timidity that I introduce this subject to colleagues who may have made a more intimate study of same.

The primary and, shall one say, the chief difficulty of the heating engineer, is to arrive within a certain degree of accuracy at the hourly amount of heat required to be supplied to attain a given internal temperature.

Quite frequently this becomes somewhat complicated, due to the construction of the building, or the application of certain materials. When such instances occur I am afraid many of us are prone to assume certain coefficients, and run a very grave risk of falling short of the temperature laid down by the client, or, on the other hand, of installing a greater amount of heating surface than necessary. But I must not for one moment suggest that the heating engineer is always to blame in the event of an installation not fulfilling the requirements. For instance, what an architect or builder may term a reasonably air-tight roof may, to the engineer, prove a serious and unnecessary heat loss.

It would be of great assistance if architects and builders would minimise, as far as possible, risks over which the heating engineer has no control.

The main object of this paper is to deal with the actual computation of heat transmission coefficients. We, as heating engineers, are quite frequently faced with the problem of ascertaining the heat transmission coefficient through a structure of compound materials, as at present it is practically impossible to procure a reference table which contains the coefficients of all materials, or combination of materials, at their various densities and thicknesses.

Let us first consider the definition of heat transmission coefficients. The quantity of heat expressed in British thermal units which is transmitted through one square foot of material, for a period of one hour and for a difference of 1° F., between the air on the inner and outerside, is called the coefficient.

The coefficient of heat transmission for any given materials depends upon the structure and density of the materials ; thus, heavy materials usually offer less resistance to the passage of heat than light materials. As a basis for computation, let us analyse the transmission of heat through a simple solid wall, as indicated in Fig. 1.

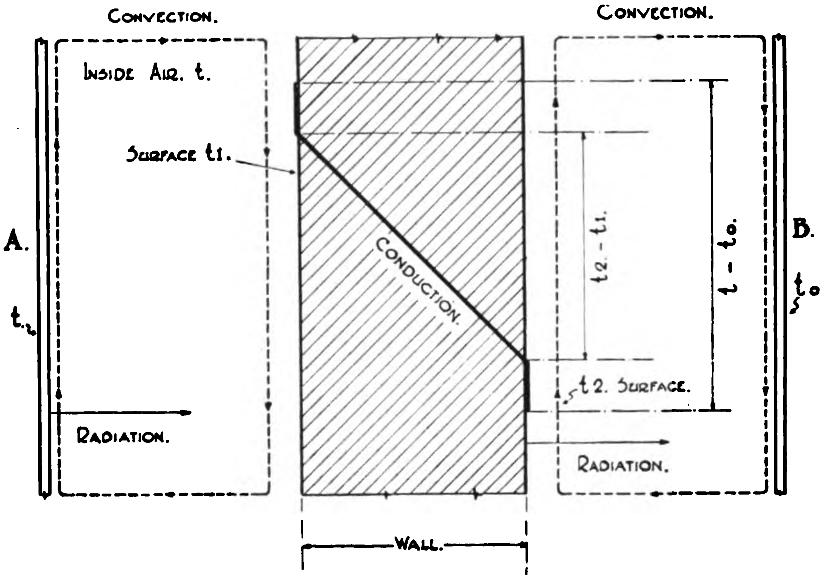


FIG. 1.

t = internal air temperature.
t_1 = temperature of inside wall surface.
t_2 = temperature of external wall surface, and
t_3 = temperature of external air.

Heat is lost from within due to same entering the internal surface of wall by radiation and convection, due to the air and objects in the room always being warmer than the internal surface of the wall, when the internal air temperature is greater than the external air temperature. The heat received on the internal surface of the wall is then conveyed by conduction to the external surface, and finally given off from the external surface by radiation and convection, providing, of course, that equilibrium has been established and that all temperatures, that is t, t_1, t_2 and t_3, are constant.

Having digested this so far, let us now consider how to compute the heat transmitted through a substance from internal air to external air, utilising Formula No. 1.

$$H = U(t - t_3)S$$

Where H = heat in B.T.U.
U = coefficient of transmission.
t = internal air temperature.
t_3 = external air temperature.
S = internal surface area of substance in square feet.

Assuming the coefficient U is unknown, it may be computed for any wall, floor or ceiling, etc., providing the values for C, K_1 and K_2 are known.

C represents internal conductivity of material.
K_1 represents the internal surface coefficient, and
K_2 represents the external surface coefficient.

The value of the transmission coefficient for a simple brick wall, unplastered, x inches thick may be attained from Formula No. 2.

$$U = \frac{1}{\frac{1}{K_1} + \frac{1}{K_2} + \frac{x}{C}}$$

and for a compound wall, that is, a wall composed of several distinct materials, having a thickness in inches of x_1, x_2, x_3, etc., the coefficient is obtained from the use of Formula No. 3.

$$U = \frac{1}{\frac{1}{K_1} + \frac{1}{K_2} + \frac{x_1}{C_1} + \frac{x_2}{C_2} + \frac{x_3}{C_3}, \text{ etc.}}$$

The value of the internal surface coefficient, i.e., K_1, for various substances in still air can, to within a degree of accuracy, be taken as 1.4 which will be seen from the following :

TABLE I.

Material	Surface Coefficient K_1	
Window glass	1.50	
Magnesia blocks	1.45	
Wood (finished surface)	1.40	
Asbestos sheets	1.40	$= \frac{9.7}{7} = 1.4$
Brickwork	1.40	
Concrete	1.30	
Corkboard	1.25	

The value for K_2, that is the external surface coefficient, under moving air conditions for various wind velocities, may be derived by multiplying the coefficient K_1 by the following factors :—

TABLE II.

Wind Velocity in Miles per hour	Factor for Brickwork	Factor for Wood	Average Factor
5	2.38	2.19	2.28
10	3.20	2.71	2.96
15	3.76	2.75	3.36
20	4.22	3.02	3.62

Where the prevailing wind velocities are unknown it may be taken as 15 miles per hour, and the factor of 3.3 used. Thus, if we multiply the value of K_1 (the internal surface coefficient) 1.4 by 3.3, the resultant 4.62 is the average value of K_2 (the external surface coefficient), and is utilised in the computation, unless known conditions make it necessary to increase this value.

The internal resistance of a material is equal to the reciprocal of its so-called internal conductivity C multiplied by its thickness in inches x, thus $\frac{x}{C}$ or $\frac{1}{C_u}$ when the conductivity is given in the terms of the construction, or thickness stated. For example, the internal resistance of a 14 in. brick wall, unplastered, on the basis of the value of $C = 5.0$ from Table III ; is $\frac{14}{5} = 2.8$ The internal resistance of a 2 in. hollow clay tile, based on the value of $C_u = 1.14$ from Table I, is $\frac{1}{1.14} = 0.877$. The sum of the internal resistances of all materials must be added to the sum of the surface resistances, which are the reciprocals of the surface coefficients, or $\frac{1}{K_1}$ or $\frac{1}{K_2}$, which equals the resistance of a surface in still air, based on the average value of K_1 or 1.4, which is $\frac{1}{1.4}$ or 0.714.

The resistance of an outside surface exposed to a 15 miles per hour wind, based on the value of K_2 or $3.3 \times K_1 = \frac{1}{(3.3 \times 1.4)} = \frac{1}{4.62}$ or 0.217

The coefficient of transmission U is now computed by taking the reciprocal of the sum of the internal and surface resistances, as indicated in Formula No. 4.

$$U = \frac{1}{\Sigma\,(R_1 + R_2 + R_3)}$$

Let us now calculate the value of U for a 14 in. brick wall, unplastered, as illustrated in Fig. 2.

Referring to Table I, we find the average value of K_1 to be 1.4 ; from Table II we find the average value of K_2 with a wind velocity of 15 miles per hour to be 3.36 times K_1, but it is sufficient for our purpose to take K_2 as $3.3 \times K_1$ in all cases, unless the average wind velocity of the site is over 15 m.p.h. Turning to Table III we find the internal conductivity of brickwork, i.e., C to be 5.0.

Now let us refer again to Formula No. 2. $U = \dfrac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{x}{C}}$ and insert the preceding values see Formula No. 2a.

$$U = \frac{1}{\frac{1}{1.4} + \frac{1}{4.62} + \frac{14}{5}} = \frac{1}{0.714 + 0.217 + 2.8} = 0.268$$

Thus *U*, 0.268 British thermal units per hour per square foot per degree F. difference between the air temperature on the two sides of the wall.

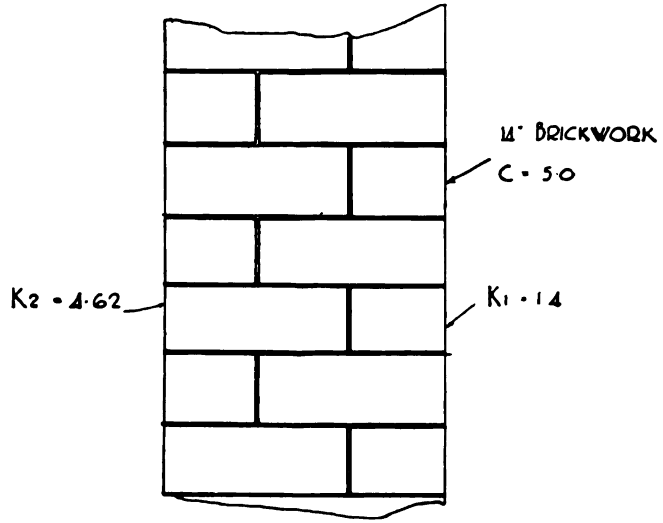


FIG. 2.

Before proceeding with a further example let us compare the internal conductivity of various building materials given in Table III.

TABLE III.

(INTERNAL CONDUCTIVITY OF BUILDING MATERIALS, EXPRESSED IN B.T.U. PER HOUR PER 1° F. per 1 IN. THICKNESS.)

Material	Description	Internal Conductivity *C*
Air	Still	0.156
Asbestos	Sheeting	0.29
Asbestos board	Corrugated	0.48
Asbestos mill board		0.843
Asbestos shingles		6.00
Asphalt		6.50
Bricks, ordinary	Dry	4.0
„ „	Damp	5.0

Material	Description	Internal Conductivity C
Bricks	Flettons	6.3
,,	Sand lime	9.2
,,	Fireclay	3.6
Cement	Portland	2.1
Cement	Mortar	8.0
Concrete	Average	6.0
Concrete	Pumice stone	1.93
Concrete	Slag	1.93
Celotex		0.33
Corkboard	Average	0.30
Cork	Compressed	0.264
Cotton		0.396
Cardboard		1.28
Gypsum	Dried	2.976
Gravel		2.568
Glass		6.46
Hair felt		0.25
Insulite	Wood pulp	0.34
Insulex	30 lb. per cu. ft.	0.90
Insulex	24 lb. ,,	0.70
Insulex	18 lb. ,,	0.53
Insulex	12 lb. ,,	0.4
Linofelt		0.28
Linoleum		1.27
Lath and plaster		2.00
Marble	White	17.28
Marble	Black	19.92
Magnesia	Boarding	0.5
Masonite	Wood fibre	0.33
Maftex	Licorice roots	0.33
Plaster	Gypsum	2.32
Plaster	Cement	8.0
Stone	Lime sandstone	6.43
Stone	Natural sandstone	10.70
Stone	Portland	10.0
Sand	Dry	2.24
Sand	Damp	7.73
Slate	Average	8.0
Sawdust	Ordinary	1.04
Shavings	Ordinary	0.707
Stucco		8.0
Sheep wool		0.336
Silk		0.332
Ten Test		0.35
Thermofelt	Not compressed	0.28
Tiles		10.00
Terrazzo		10.00

Material	Description	Internal Conductivity C
Wood	Oak	1.30
,,	Virginia pine	0.958
,,	White pine	0.784
,,	Yellow pine	1.00
,,	Balsa	0.4
,,	Teak	1.212
,,	Cypress	0.688
,,	Fir	1.00
,,	Maple	1.2
,,	Mahogany	0.90

MATERIALS IN MANUFACTURED THICKNESS

	C_u
2 in. Hollow clay tile	1.14
4 ,, ,, ,, ...	0.65
6 ,, ,, ,, ...	0.5
8 ,, ,, ,, ...	0.43
12 ,, ,, ,, ...	0.26
16 ,, ,, ,, ...	0.185

Continuing with the examples let us now calculate the value of U for a wall of compound structure, as illustrated in Fig. 3.

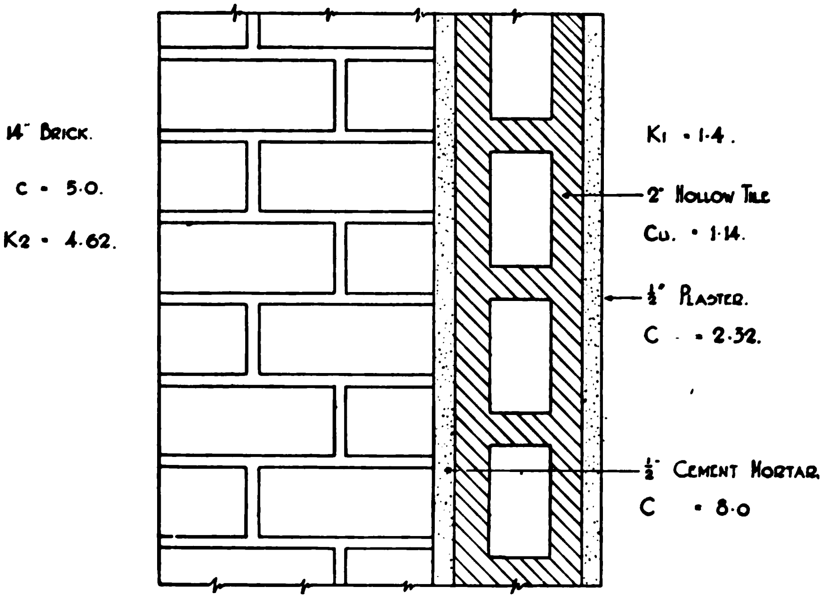


FIG. 3.

Using the same internal and external surface coefficient as in Formula No. 2a, i.e., $K_1 = 1.4$ and $K_2 = 4.62$, we refer again to Table III and find that the internal conductivity C of brickwork is 5.0, cement mortar 8.0 and plaster 2.32, whilst the internal conductivity C_u for the thickness stated of hollow clay tile is 1.14. Applying Formula No. 3 to suit our requirements in this instance we write this down as follows. (See Formula No. 3a.)

$$U = \frac{1}{\frac{1}{1.4} + \frac{1}{4.62} + \frac{14}{5} + \frac{0.5}{8.0} + \frac{1}{1.14} + \frac{0.5}{2.32}}$$

$$= \frac{1}{0.714 + 0.217 + 2.8 + 0.062 + 0.877 + 0.021} = 0.213$$

Therefore the coefficient of transmission for the above example per hour per square foot per degree F. difference between the air on the two sides of the wall is 0.213 B.T.U.

To find the value of U for a sheet of glass ⅛ in. thick, utilising Formula No. 2 and the same values for K_1 and K_2, we have (see Formula No. 2b):

$$U = \frac{1}{\frac{1}{1.4} + \frac{1}{4.62} + \frac{0.125}{6.46}} = \frac{1}{0.714 + 0.217 + 0.019} = 1.05$$

Thus the heat loss through a sheet of glass ⅛ in. thick per hour per square foot per degree F. difference on two sides equals 1.05 B.T.U.

To compute the coefficient U for a combined ceiling and pitched roof or unheated attic, as indicated in Fig. 4.

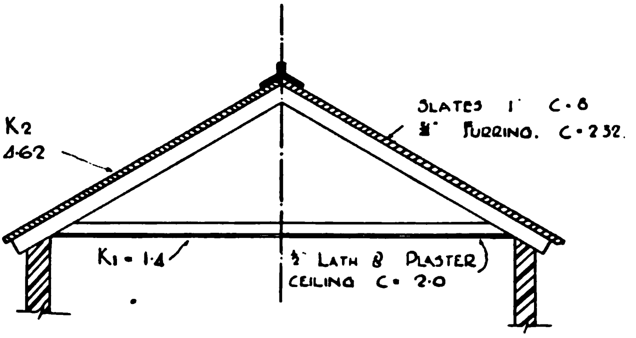


FIG. 4.

we calculate the value U for the ceiling and also for the roof, in accordance with Formula No. 2 or No. 3 as the case may be, but in this instance both the ceiling and roof must be taken into consideration, and the combined coefficient of transmission determined, which necessitates the use of Formula No. 4.

$$U = \frac{U_r \times U_{ce}}{n \times U_r + U_{ce}}$$

Where U_r = coefficient of transmission of the roof.
U_{ce} = coefficient of transmission of the ceiling,
and n = the ratio of the area of the roof to the area of the ceiling.

As an example, the coefficient U of the roof illustrated in Fig. 4 (see Formula No. 3b) is :

$$\frac{1}{\frac{1}{1.4} + \frac{1}{4.62} + \frac{1}{8} + \frac{0.75}{2.32}} = 0.72 \text{ B.T.U./sq. ft./ } 1°\text{diff./hr.}$$

Likewise the coefficient U for the ceiling also illustrated in Fig. 4 (see Formula No. 2c) is :

$$\frac{1}{\frac{1}{1.4} + \frac{1}{1.4} + \frac{0.75}{2.0}} = 0.55 \text{ B.T.U./sq. ft./}1° \text{ diff./hr.}$$

In this instance it will be noted that both the internal and external surface coefficients for the ceiling are for *still air*, i.e., K_1 and $K_2 = \frac{1}{1.4}$ respectively.

Continuing, we apply the coefficient U which we have obtained to Formula No. 4, and the value of n, that is the ratio of roof to ceiling, is, for the purpose of this example, taken as 1.3. Thus we write (see Formula No. 4a) :

$$U = \frac{0.72 \times 0.55}{1.2 \times 0.72 + 0.55} = 0.26$$

Thus the combined coefficient of transmission for a slate and furred roof with lath and plaster ceiling with a ratio n of 1.3 = 0.26 B.T.U. per square foot of ceiling per degree F. difference between the air on the inner side of ceiling and outer side of roof.

Having discussed the actual computation of the coefficients of transmission, the next procedure is to consider the mode of application to arrive at the hourly heat loss from a building by transmission through all surfaces which separate heated spaces from unheated spaces. This loss is derived by multiplying the areas in square feet of the wall, floor, roof, ceiling, glass, doors, etc., by the coefficient U, and by the temperature difference between the inside or heated air temperature at the correct level, not always breathing line, and the unheated or outside air temperature.

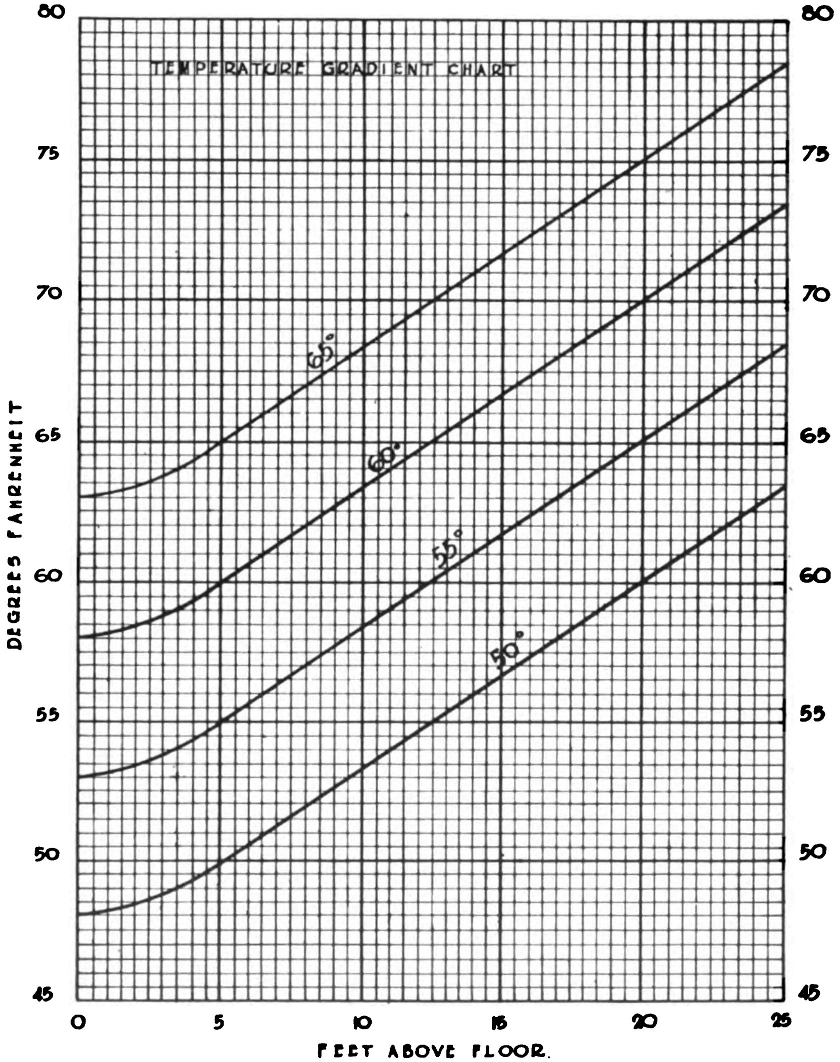
It must be borne in mind that the inside temperature varies with increasing height above the floor, but for practical purposes the increase of temperature up to a height of 10 ft. may be neglected, providing that the roof loss coefficient U is not unduly great. For greater heights the temperature may be approximated by Formula No. 5.

$$t^1 = t\,[1 + 0.017\,(h - 10)] \text{ when } t^1 \overset{=}{<} 1.3t$$

where t = temperature in degrees F. at breathing level,
and t^1 = temperature in degrees F. at a distance h ft. above floor.

but for convenience may be derived from the following chart, which indicates the gradients for basic temperatures of 50°, 55°, 60°, 65°.

As an example let us consider a room 17 ft. from floor to mean height of roof, on a basis of 60° F. at breathing line and 32° F. outside.



	Area		U		$t_1 - t$		
Floor	28500	×	0.25	×	10	=	71250
Wall	7685	×	0.33	×	31	=	78678
Roof	22800	×	1.45	×	36	=	1190160
Roof light	12540	×	1.2	×	36	=	541728
Air	527250	×	0.019	×	Average internal diff. temp. 32°	=	314176
							2195992

Were the above example calculated throughout on the mean average temperature, the total hourly heat loss would amount to 2.041,723 B.T.U., and thus show a deficiency of 154,267.

Finally, it is necessary to consider the heat loss prior to attaining equilibrium. This additional allowance may, for average-sized rooms heated during the day-time but discontinued at night, be computed from the use of Formula No. 6.

$$Z = \frac{0.063 W_1 (n - 1)}{D}$$

where Z = allowance in B.T.U. for heating-up,
W_1 = B.T.U. lost per hour through outer walls, windows and roof.
D = duration of heating-up period in hours,
and n = the number of hours for which the heating is discontinued.

For instance, if the heat is turned on at 6 a.m. and the final temperature is reached at 8 a.m., D would equal 2 hours. Again, if the heating is discontinued after 5 p.m. then n equals 12 hours.

Take, for example, a school equipped with an oil-fired heating installation, which starts up automatically by means of a time switch at 6 a.m. the final internal temperature of the building must be attained by 9 a.m. and the heat is again cut off at 5 p.m.

Assume a classroom with an hourly heat loss of 25,000 B.T.U., excluding heating of air contents, applying Formula No. 6 it is found that an additional 5,775 B.T.U. are required per hour for the classroom in question, prior to attaining the steady state, this would entail the installation in this instance of approximately 20 per cent. more heating surface.

In the case of churches or halls used for only short periods, it is possible to raise the air internally to the required temperature normal under the circumstances, also the cooling of the room is effected more rapidly upon discontinuing the heating. Therefore under these circumstances no great loss can take place, only a part of the wall thickness absorbs heat, and the only heat loss of any moment is that transmitted through glass. The determination of the heat loss may, when the heating surfaces are favourably distributed, be derived from the use of Formula No. 7.

$$W = \frac{FK\,(t - t_0)}{2} + F_1\left(8.5 + \frac{t - t_1}{Z}\right)$$

and when the heating surfaces are unfavourably situated from the use of Formula No. 8.

$$W = \frac{FK\,(t - t_0)}{2} + F_1\left(15 + \frac{2(t - t_1)}{Z}\right)$$

where W = heating requirement in B.T.U. per hour,
F = glass surface in square feet,
F_1 = superficial area of walls, ceilings, floors, pillars, etc., in square feet,
K = transmission for glass per hour per square foot per degree F. difference,
t = required inside temperature in degrees F.
t_1 = initial room temperature when heating-up occurs,
t_0 = lowest outside temperature,
and Z = heating-up period in hours.

For the purposes of calculation, the heating-up period may be taken as six hours, and for rooms exceeding 40 ft. in height 5 per cent. should be added to the heating requirement for every additional 3 ft. in height. As an example, let us ascertain the amount of heat required per hour to attain the normal internal temperature for a short period only. We can compare the results with the previous example, where the hourly heat required was 2,195,992 B.T.U. Utilising the same areas, etc., and allowing a heating-up period of six hours, we find from the use of Formula No. 7 that only 936,827 B.T.U. are required per hour, approximately half of the original amount. This, I think will explain the reason that in some cases where it is definitely known from calculation that the heating surface installed in a building has been decidedly underestimated, the desired internal temperature is attained, but it is certainly not maintained.

If, therefore, you should hear of some poor unfortunate who has fallen short in estimating his B.T.U., it would be a kindly action to advise him when testing to beat a hasty retreat, and take to his heels whilst the temperature is at its peak.

In conclusion, I hope that I have said sufficient to indicate how complicated is the question of heat transfer from buildings, and whilst I am anxious that a full discussion should follow, I must crave your indulgence when questioning me on specific details. If I have brought this subject to your notice in such a manner as to cause further thought to be given to this question in the immediate future, then perhaps some small service will have been fulfilled.

DOMESTIC HOT-WATER SUPPLY FOR LARGE BUILDINGS

By F. R. L. WHITE (Associate Member)

ASSOCIATE MEMBERS AND GRADUATES SECTION

BIRMINGHAM, FEBRUARY 14th, 1934

THE subject of the production and distribution of hot-water supply is one which has received little, if any, serious consideration by our authors of technical works.

There is a number of excellent volumes to be obtained, dealing with the wide variety of subjects with which the heating engineer is concerned, but few treat this subject in more than a cursory manner, and most do not mention it at all.

It is not until one is faced with a really large job, bristling with difficulties, that one fully realises this significant fact, and under such conditions one is thrown very much upon one's own resources.

When in such a predicament, there is always in the background that comfortable feeling that first principles still remain, and if applied with common sense and care they can be used to solve most, if not all, of our problems.

With this in mind, it appears to be a fairly simple job to tackle the design of hot-water supply installations upon a reasonably sound and reliable basis. For the rest, one must profit by the practical tests made upon the plant installed under one's supervision, and make any adjustments which may from time to time appear to be necessary.

A hot-water supply apparatus should be considered as consisting of four distinct and equally important parts. Firstly, the heat-producing unit comprising either a boiler and storage cylinder, or a storage-pattern calorifier, or in some cases a separate calorifier working in conjunction with a storage cylinder. Secondly, a system of pipes which shall be called for convenience the flow pipes, the duty of which is to provide adequate passage for the heated water to all taps, towel-rails, linen-coils, and other sanitary appliances. Thirdly, a system of return pipes properly proportioned so as to provide complete circulation of the hot water to within close proximity of all points of service, either by gravity flow, or with the aid of an accelerator. Fourthly, a cold-water supply and expansion tank, complete with feed pipe to the apparatus, and automatic supply valve, the duty of which is to displace the hot water from the installation.

Each of these four parts, is, in reality, a separate unit, and will be dealt with as such.

It is not an easy matter to lay down a hard and fast rule for sizing the boiler and cylinder, as obviously different types of buildings have different conditions to be satisfied.

Common practice dictates that a bath requires 25 gallons of water per hour, a sink 10 gallons per hour, a lavatory basin 2½ to 3 gallons per hour, and a shower bath 20 to 40 gallons per hour, according to the type of building, with the hot water at a temperature of 150° F. It must be evident that these figures are purely arbitrary, and as such must be used with great caution.

For instance, when dealing with public bathing establishments, at rush periods each bath may be used three times per hour, and if each bather is allowed 15 gallons of water at 150° F. this would call for a total of 45 gallons per bath, per hour, perhaps for three or four hours at a stretch.

Then again, in mental hospitals it is customary to set certain days apart for bathing parades, and at such times the baths are in continuous use throughout long periods, often at the rate of four baths per hour.

In laundry work, large quantities of hot water are required to be discharged into the machines in very short intervals of time. It is sometimes necessary to allow for flows at rates anything from 50 to 70 gallons per minute, for this purpose into a single machine.

It will be obvious, therefore, that very careful particulars of the working conditions must be taken before deciding upon the basis of calculation.

Unless any such special circumstances prevail, it appears that the figures first mentioned may be used as a basis for calculation of the number of gallons of hot water to be provided per hour. It will be obvious, however, that the total connected load would not be likely to operate at any one time, and a load factor should be assumed. This appears to be in the case of residences about 50 per cent., and in the case of public institutions about 75 per cent. of the total connected load, but here again, local conditions must guide us in fixing the actual factor, by a commonsense survey of the estimated working conditions, preferably in collaboration with the person or persons responsible for the administration.

The size of the storage cylinder would then be fixed by the actual hourly demand, i.e., as fixed by the load factor, and it is not good practice to allow for less than one hour's draught in fixing this storage capacity. It should be borne in mind that in a large installation, the mains form a very large reservoir for the storage of the hot water, and their capacity should be calculated and deducted from the storage capacity of the cylinder.

The boiler will be required to supply the necessary B.T.U. to heat up the calculated quantity of water from say, 50° F. to 150° F., but it will also be required to supply the additional B.T.U. to compensate for the loss of heat in transmission from the piping, towel-rails, linen-coils, etc. This is a very considerable factor in a large apparatus, and it complicates the procedure in fixing upon the size of the boiler.

Hot-water boilers have two distinct ratings, one for central heating, and another for hot-water supply. Our boiler has to deal with both types of apparatus simultaneously, in effect. How, then, are we to fix the size of it?

Investigators do not appear to have settled this problem satisfactorily up to the present, and in view of this fact, one must fall back upon one's own devices.

Boilers are rated usually at about 7,000 to 11,000 B.T.U. per sq. ft. of boiler heating surface for hot-water service, and at about 4,400 B.T.U. per sq. ft. for central heating. If, therefore, the B.T.U. required for heating purposes are divided by 4,400 and those required for hot-water supply are divided by 7,000 to 11,000, aggregate boiler heating surface thus found would appear to be reasonably near to our requirements.

It is not suggested that this method is scientifically accurate. The problem is very much more complicated than this, but it is suggested that a result thus obtained is nearer to the mark than a mere guess, a shot in the dark.

This matter is one which, I think, boiler-makers might take up quite seriously, as these large hot-water plants are very definitely things of the future.

If a calorifier is to be used, we find ourselves up against a similar difficulty. We rely upon manufacturers to put forward a heating battery of ample surface to properly meet our demands, but here again, the coefficient of transmission seems to be a thorn in the flesh. Quite recently in my own experience an enquiry was put out for a heating battery to raise 1,000 gallons of water per hour from 50° to 150° F. with steam at 60 lb. per sq. in. pressure. Three separate firms gave the battery as 26, 32 and 35 sq. ft. respectively, and as they all proposed to use plain copper U-tubes as the heating surface, it seems difficult to reconcile these results one with the other.

It is, of course, apparent that the coefficient of transmission of heat from the steam to the water, has not been investigated so far as to be able to standardise it.

Furthermore it appears to be common practice to use the arithmetic mean temperature difference between the heating medium and the heated liquid. This is, of course, one source of error, and, bearing in mind always that we are particularly concerned with large installations, the error may be large enough to produce results very embarrassing to the contractor.

In all such calculations, the logarithmic mean temperature difference should be used, and in case anyone is not fully conversant with this formula, it is as follows :—

$$\frac{(T_{p1} - T_{sf}) - (T_{p2} - T_{sr})}{2.3025 \log. \left(\dfrac{T_{p1} - T_{sf}}{T_{p2} - T_{sr}}\right)} = T_m$$

Where T_m = mean temperature difference between steam and water.
T_{p1} = initial steam temperature.
T_{p2} = final steam temperature.
T_{sf} = flow temperature, water.
T_{sr} = return water.

The result of the use of this formula gives a mean temperature difference between the steam-heating medium and the water to be heated, which, when multiplied by the coefficient of transmission for the type of heating surface in use, will give the rate of transmission per sq. ft. of heating surface, and the amount of heating surface necessary by simple division into the total B.T.U.

Having fixed the size of the boiler and cylinder, or of the calorifier, it remains only to agree with the purchaser as to the form of protection to be adopted against breakdown. Duplication of both boiler and cylinder is, of course, to be advocated strongly, but if first cost is a stumbling block, it certainly would not be prudent to allow for less than an arrangement whereby each boiler and each cylinder would be capable of performing two thirds of the total duty.

In the case of hospital work, duplication should be insisted upon most rigidly.

Now for the second part of our plant, the flow-pipe system. This part of the plant must be designed in such a way that every point of draw-off is adequately supplied by gravity flow with the correct quantity of water, and under maximum conditions. In a hospital particularly one could not tolerate the spectacle of taps on upper floors ceasing to function when taps on lower floors are opened. Yet such conditions do exist in some buildings even in these enlightened days.

The all-important point to be considered in this part of the design is the rate of flow, quite apart from any consideration of circulation.

Consider the ordinary bath. It takes about 35 gallons of hot and cold water to provide the average person with comfortable bathing facilities, of which we may assume that 17 gallons would be required at 150° F. and 18 gallons at 50° F. A reasonable time for filling the bath would appear to be four minutes, so the rate of flow for the hot tap would be 17 gallons in four minutes, or 4.25 gallons per minute.

In the case of a lavatory basin of normal dimensions, the amount of water required for one washing would be about 0.8 gallons and the time for filling should not exceed 30 seconds. Thus the rate of flow would be 1.6 gallons per minute, made up of 0.75 g.p.m. of hot water at 150° F. and 0.85 g.p.m. of cold water at 50° F.

In a similar manner the rate of flow for a sink may be calculated as 3 g.p.m. for both hot and cold taps, assuming a sink 30 in. by 18 in. by 10 in. deep, with 12 gallons working capacity, and filled in two minutes.

With shower roses, the manufacturer's data usually includes a reference to the amount of water which the roses will pass in a given time, so that the rate must be fixed according to the type of shower plant which is to be adopted.

The same remarks would, of course, apply in the case of specialised fittings, such as sterilising equipment, bed-pan washers, laundry machines, dish-washers, and the like. Particular attention should be given to these items, as in many cases, the rate of flow into this type of equipment, is high.

Having fixed upon the various rates of flow, the next step is to figure out on the scheme sheet the number of gallons per minute which each draw-off, branch and trunk main is to carry.

The head available to cause flow through the mains to any particular branch, is the difference in level between the cold-water feed tank and the highest point of draw-off on the particular branch, and the travel of the water in reaching the draw-off, will, of course, be the measured distance through the feed pipe, plus the total travel from the cylinder, including allowance for change of direction in fittings.

The rate of flow would depend upon the relation between these two quantities, available head and travel, and the relation between all the factors mentioned is given by the formula computed by Thos. Box, namely :—

$$h = \frac{G^2 \times L}{(3d)^5}$$

$$d = \sqrt[5]{\frac{G^2 \times L}{h}} \div 3$$

In this formula—

G = gallons of water flowing per minute.
L = length of pipe in yards including allowance for bends, tees, etc.
h = available head of pressure in feet.

The formula may be reproduced either in graph or tabular form for convenient use in rapid calculations.

Each separate branch main should be sized in accordance with its own flow factor, but the trunk mains should be sized upon the least favourable factor of all the branches which they serve.

Trunk mains may be sized to carry from half to two-thirds of the total connected load, whilst branches should have about two-thirds the full carrying capacity, and draw-offs, of course full size.

It depends upon the type of building as to what allowance should be made in the trunk mains. For instance, if the building is a hospital, in the nurses' home block where all the day staff would be likely to use the wash-basins and baths together, and in a short period of time the mains would be required to have about two-thirds full capacity, whereas in a ward block where the washing is spread over about an hour, the mains may be required to operate at about one half of the total capacity.

This peak-load factor, expressed as a percentage of the total connected load is a vital factor in design, but one upon which we have very little statistical backing.

It will be realised that as the factor varies for each building, according to its usage, the peak-load factor on the centralised mains serving several blocks of buildings would have to be fixed after a careful survey of each and all of the load factors throughout the maximum draw-off periods.

By noting the rate of flow on each subsidiary main at say, half an hour intervals during the known rush periods, and then totalling up the rate of flow at each half hour, a peak-load factor for the rate of flow on the trunk main can be detected and the main sized accordingly.

Having thus sized all the flow mains, there is now a basis upon which to commence the third stage of the design, namely the return mains.

These mains should be sized in such a way that they are capable of passing sufficient water in circulation to provide for the loss of heat in transmission from the mains, the towel-rails, linen-coils, or any other form of heat transmitting surface which may be coupled in circuit with the system.

The transmission losses from the flow mains should be jotted on the scheme sheet for each section of the mains, including the losses from the heating surfaces mentioned above.

The head at which the pump is to work should then be fixed, always bearing in mind from a maintenance point of view, that high pump heads mean high consumption of electrical energy. The working head must, therefore, be fixed at an economic level compatible with the size of the job in hand, and after making allowance for the head losses in the connections around the pump, the remaining head loss may be distributed throughout the pipe line.

Obviously, the head lost in the flow mains would be very small, since comparatively large pipes are employed to convey the hot water at a low rate of flow, for the purpose of overcoming the heat losses only. It is an easy matter to calculate the actual head lost in the flow mains, in the same way as for an accelerated heating plant.

The balance of head left after deducting both the losses for the pump connections and the flow main is the head available for circulating the water through the return mains, which may then be sized according to the amount of water which each section is to convey. The losses from the return mains themselves, must, of course, be allowed for when sizing up.

A final check on the head losses throughout the entire system may then be made and the pump head adjusted accordingly if necessary.

It may be of interest to mention here that in calculating the return pipe sizes, the formula already mentioned, i.e., that by Thos. Box, should not be used, as the head losses thus calculated are for pipes with free discharge, as distinct from closed circuits. There are several dependable formulæ available for this calculation from which charts may be constructed for ready use. It should be remembered, however, that the frictional resistance of iron pipes is about 23 per cent. higher than that of copper pipes. Due allowance should be made.

It is usual to arrange for the pump to circulate the water with a temperature drop of 20° between flow and return temperatures. It should, of course, be connected in the secondary return mains, with a by-pass and isolating valves. A duplicate pump should, wherever possible, be fitted, and where conditions will allow, one pump may be arranged with electric-motor drive, while the other may have a steam-driven turbine as the prime-mover. This arrangement guards against stoppage due to failure in the electric supply.

There are many who recommend that the pump should operate on the flow main, but it seems that this arrangement is conducive to partial failure for two good reasons. First, it would appear to restrict the free flow of hot water for draw-off purposes, and secondly, it would leave free access for water to tend to be drawn-off up the return main, a contingency which should be rigidly guarded against.

In a correctly designed hot-water installation the flow mains will naturally be of much greater sizes than the return mains. It would be quite practicable to find a 4 in. flow main paired up with 1 in. or 1¼ in. return main, if the proportion of water for draw-off purposes to that for heat losses happened to be a high one.

In earlier days it was the custom to make both the flow and return mains of the same size, and usually the sizes were judged by so-called experience.

A little later it was considered quite safe to make the return one size less than the flow main, and in both these arrangements it was considered that water would be served to the taps from both the flow and the return mains. How many of us at some time have not been troubled with the old bugbear of cold water running from the hot tap, when there has been quite a good storage of hot water in the cylinder. This was, of course, in nine cases out of ten, due to the fact that the return main was too large. Water, like all other things, will flow in the path of least resistance. The obvious remedy, therefore, is to introduce resistance in the form of small pipes, in all paths along which one does not wish the water to travel, and thus guide the water into the correct channels. If the flow mains are correctly sized to pass the full quantity of water for draw-off purposes without any reference to the return mains at all, then the possibility of backing up the return main will be almost, if not entirely eliminated.

All that now remains to complete our design is the cold-water feed system. You will remember that this part of the plant was described as carrying out the duty of displacing the hot water from the apparatus. In a large installation it will be prudent to collaborate with the architect in the very early stage of the job, upon this very important point.

It is usually necessary to provide a tower, or some other elevated position to accommodate the supply tanks, both hot and cold, and it is most essential that there is ample working head between the bottom of the tank and the most elevated sanitary appliance which has to be supplied with water. Otherwise the supply pipes will be of such large sizes as to be cumbersome and costly in initial outlay and in maintenance.

The margin of head available should never be less than 20 ft. for a large building, and as much more as practicable.

The size of the tank will entirely depend upon local conditions. If a town water supply from a dependable source is available on tap, and at a good pressure, then the tank need not have a greater capacity of more than one hour's supply, due allowance being made, of course, for the water ejected from the apparatus as a result of expansion, and for the space required in the tank for the operation of the automatic float valve. If the water has to be pumped to the tanks daily from a private source such as a well or reservoir, then the tank should not have a lesser storage than about 24 hours' supply. The failure of the supply to the tank must always be regarded as a contingency to be carefully guarded against. Shortage of water in a hospital particularly may result in very serious consequences.

Wherever possible, the tanks should be duplicated, or if a sectional tank is used, it should be constructed in two water-tight compartments, connected together and valved externally, for obvious reasons.

A bell-mouthed overflow pipe is preferable to the ordinary side outlet connection, as the full area of the overflow pipe is available for passage of the overflow water immediately the level reaches the bell mouth.

Now with regard to the feed pipe to the apparatus. It is an undoubted fact that many failures in an otherwise well-designed apparatus, may be traced to faulty sizing of the feed pipe.

The rate of the flow to the apparatus must be the same as that from the apparatus, and it is therefore evident that the feed pipe should be the same size as the flow pipe, or as the combined capacities of the several flow pipes if such there are. It should be carried from the tank direct into the bottom of the cylinder, and a diffusing pipe should be fixed within the cylinder to direct the flow of cold water along the bottom of it.

This is a controversial point. Some advocate that the feed should enter the system in the return pipe on the suction side of the pump, with the object of reducing the head on the tank.

Such an arrangement appears to take no account of two other, and to my mind, much more important factors. First, the free flow of water for draw-off purpose is restricted by reason of the fact that the pump connections are necessarily very much smaller than the feed pipe and of the flow pipe. Secondly, it seems almost unavoidable that the pump should pick up a cold jet of water and force it straight through the cylinder into the flow main.

Just two more points in connection with the feed pipe. When measuring the length of any flow main, the total travel should include also the length of the feed pipe, because the feed pipe really forms part of the flow system.

If the feed pipe works out to a large size, it may be wise to consider running two smaller pipes in parallel, with a combined capacity equal to, or a little above the large pipe. This would guard against complete stoppage in case of breakdown.

Although this paper purports to deal with large scale domestic supply work principally, the same general arrangements would, of course, be adaptable to small plant.

The chief essential difference would be in the sizing of the return mains. The circulating head available in this case would be derived from the elevation of the heat transmitting surfaces above the cylinder or calorifier, and the return mains would therefore be much larger in proportion than for an accelerated system, and would need to be very much more carefully proportioned.

There are one or two special requirements in connection with hot-water service supply upon which it may be of interest to comment.

In large kitchen work it is generally required to have a separate source of hot-water supply at a higher temperature than usual for the washing of greasy dishes and plates. This may be met in several ways, but where a steam main is run to the main kitchen for service to the cooking plant, the most convenient method is to fix a small calorifier in or adjacent to the wash-up. This calorifier may either heat up the water from cold to the desired temperature of about 180 to 190° F. or it may take the form of a reheater, with its supply from the central hot-water supply main, according to the local conditions. If steam is not available, then a gas-heated or electrically-heated unit should be fixed for this purpose.

Then in connection with flannel washing machines in the laundry it is essential that the water should not exceed a temperature of about 100° F., otherwise shrinkage of the garments would result. It is therefore usual to supply a small tank with a steam coil in it, controlled by a thermostat set at the predetermined temperature. The tank should be at least of a size as will supply a full charge of water to each machine every half-hour at the right temperature, and the coil should be capable of supplying the necessary heating power in the same period. The tank will be supplied with cold water from the cold-water service main giving general service to the laundry, and will be under automatic float-valve control.

The shower bath and water blender also need special treatment insofar as the hot- and cold-water supply pressures must be the same, and if they vary at all they must vary in unison. The safest way of ensuring this condition is undoubtedly to run the cold-water main to the showers from the same cold-water tank which feeds the hot-water supply. Thus, if the head from tank water-level varies, it varies equally on the hot and the cold-water connections. This is an important matter. I have seen cases where cold water has backed up hot-water mains through the operation of mixing valves, and actually overflowed the hot-water supply make-up tank at full bore.

Several forms of reflux valve have been incorporated in mixing valves, but it will be appreciated that whilst these valves may prevent backing up of water from one main to the other, they nevertheless interfere with the proper blending of the water. If the water pressures are out of balance, the reflux valves may remain closed for considerable periods, or partially closed, so that the proper admixture of the proportions of hot and cold water cannot effectively take place, at all times during the operations of the mixer.

Time does not permit of more than this brief survey of a very interesting subjcct, but in conclusion may I commend to your consideration one or two points which arise from this paper?

It is suggested that the following matters may well be the subject of practical research, which is within the scope of all of us to carry out.

1. The re-rating of domestic hot-water boilers, to cover a series of duties such as are met with in large-scale hot-water service supply work. It is obvious that where large proportions of heating losses exist in the apparatus, the present catalogue ratings are misleading.
2. The collection of data in regard to the consumption of water in bulk in different types of buildings, and the periods at which the maximum quantities are used.
3. A survey of the rates of consumption of hot water in various types of buildings, particularly in regard to the maximum flow likely to be obtained, relative to the total connected loads, with a view to fixing the elusive load factor. This, of course, would go a long way towards solving the pipe-sizing problem, so far as marginal allowance is concerned.

The first problem is one mainly for the boiler-makers, but the other two are for the co-operation of all in establishing valuable practical data. They are not and never will be laboratory matters, but matters which can only be investigated in actual practice under the severest test of working conditions.

It is suggested that wherever recording and integrating meters can be fixed they should be, and full use should be made of them. Almost invariably, on large contracts, the heating engineer is in touch with the client for at least twelve months after the actual completion of the contract, and during that time it should be an easy matter to obtain a series of readings from the meters under the actual working conditions. These readings could then be compared with the data relating to the design and any adjustment which may be necessary would at once be apparent.

With the co-operation of all who have the future welfare of our industry at heart, it should be possible to collect a very valuable amount of data together, to the mutual advantage of both the engineer and the client.

AIR CONDITIONING IN INDUSTRY

By H. W. HALL (Associate Member)

ASSOCIATE MEMBERS AND GRADUATES SECTION

MANCHESTER, FEBRUARY 13th, 1934

It is not intended in this paper to cover every industry, although it could be said truthfully that air conditioning is of benefit to the majority of industries. There are, however, certain trades where it is of great benefit, and the cost of installing and operating equipment with first-class regulation results in working economies which amply justify the corresponding investment and expense of operation. Manufacturers have realised during the last few years the tremendous advantage to be gained by the correct application of air conditioning to their particular branch of manufacture, both from the healthier condition of their operatives and from the minimum of bad work due to bad atmospheric conditions.

It is necessary to first explain the general principles of air conditioning before describing their application.

The harmful effects of bad air were recognised by men centuries ago, and they resorted to the most simple antidote by diluting it with fresh air. This was the origin of the art of ventilation. As time went on and the outside air became charged with chemicals, etc., due to the growth of industry, problems arose which demanded an analysis of causes and effects. The amount of fresh air required and the conditions under which it must be supplied are moot questions which have puzzled engineers for years.

To clear these questions it is first necessary to determine just why and how, fresh air affords relief. Modern science asserts that respiration has little to do with the ventilation problem and that the ill-effects produced in badly-ventilated rooms are due to the physical properties of the air, namely temperature, humidity and activity. Man is a warm-blooded animal, and to maintain life it is necessary to keep the body temperature uniform. Obviously the heat generated by the body must be dispersed, some of the heat generated is lost through respiration and excretions, but most of it is dispersed through the skin to the surrounding atmosphere. The rate at which this heat is transferred to the air depends upon the physical condition of the latter.

Evaporation is the supplementary process by which heat is dispersed from the body. Air can only absorb a limited amount of moisture. The amount it actually contains at a given temperature, as compared to the amount it could hold if saturated is called the relative humidity of the air. If the temperature is increased it expands and its saturation limit is increased, consequently, unless water is added, its relative humidity is lowered. This is why moist air becomes dry when heated. If the air in a room is too dry the occupants feel cold, even though the temperature is correct; on the other hand if the air is too moist the occupants will feel too warm even though the temperature is correct. It therefore follows that temperature is as equally important as humidity and vice versa. The only way, then, to give both correct temperature and humidity in the room is by the proper application of an air-conditioning plant. I do not intend to go into details regarding the construction of these plants, as they can be found in any good text-book on the subject. It is the correct application of these plants to industrial processes that I propose to explain as follows.

The Textile Industry

The proper application of air conditioning in a textile mill results in consistent, permanent financial gain. In processing raw materials from the original state to the finished fabric, very light fibres are drawn through the air in various types of machines. The heat generated in certain machines is relatively great, the tendency is, therefore, to evaporate, or give off moisture, and, if possible, this must be prevented or the material is impaired in quality. This is prevented by having the air through which the material is processed, at such a temperature and relative humidity that the equilibrium of moisture between material and air is not overbalanced causing a flow from material to air, but that it is slightly the other way, thus assuring the correct amount of moisture being retained in the stock. The determination of the proper rate of evaporation for maintaining the required humidity and temperature in each department of a factory is a problem for an expert. Air-conditioning plant should not be purchased as if it were merchandise. The value which the purchaser ultimately receives will depend not so much upon the type of apparatus, or the number of units which it comprises, but upon the ability of the plant as a whole to deliver the total evaporative capacity required in a satisfactory manner. The textile industry embraces much of craftsmanship as well as art, since these elements are of foremost importance in making merchantable fabrics, it was not until recent years, when the urge of competition forced the use of more commercial methods, and the acquiring of hitherto unattainable effects, that a really scientific and technical background began to develop; and the problem of providing standard conditions of humidity, temperature and motion in various stages of textile production has become the subject of special study by all progressive industrialists.

Under average conditions all textile fibres are capable of holding a large amount of water in mechanical suspension, if the temperature of the material is increased this water can be driven-off, but immediately the material is restored to a normal atmosphere it will regain an amount of moisture equal to that which it originally contained. The natural moisture content expressed in terms of relative humidity of cotton in the natural state are as follows :—

American	cotton	9.4 per cent.
Egyptian	,,	8.6 ,, ,,
Indian	,,	7.6 ,, ,,

It is usual to impart a certain amount of water to cotton by artificial means, this prevents any difference in the selling prices per pound due to some having large amounts of moisture and others very little. The amount of water added in this way is called the regain, and the maximum amount permissible for cotton is 8.5 per cent.

In the bale stores of cotton mills there is always a loss in weight due to the evaporation of the natural moisture content of the cotton. If air-conditioning plant is installed this loss can be prevented, and it is usual practice to keep the room at a temperature of 72° F. with a minimum relative humidity of 65 per cent. In the scutching room there is a considerable amount of moisture lost due to the scutcher fans extracting the air and delivering it into the dust flues, this loss must be compensated for when designing the plant, and a relative humidity of 70 per cent. at a temperature of 70° F. is desirable. In the carding and spinning processes the object of air conditioning is not to add further moisture to the material, but to prevent any loss of moisture that has been previously imparted to the material. In the card-room there is a large amount of static electricity generated which causes the fibres to become brittle and less workable. The best conditions for satisfactory card-room operations are a relative humidity of 60 per cent. with a temperature of 70° F., depending on the class of material. In the spinning processes there is a large amount of heat generated, and it is necessary to adequately ventilate the room as well as condition the air. For mule spinning, a relative humidity of 55 per cent. at a temperature of 80-85° F., and for ring spinning a relative humidity of 60 per cent. at a temperature of 75° F. are good working conditions, there is a slight variation necessary due to the counts being spun, lower for fine counts, higher for coarse counts. The physical properties of textile fibres change for the worse as they become dry, they become brittle and less workable. It is necessary to maintain a fairly high temperature for all cotton processes in order to maintain the fibres in the requisite pliable condition.

In the woollen industry it is not a generally accepted fact that air conditioning is necessary. This is quite opposite to the opinion held by the cotton branch, where it has been recognised for a long time that a cotton mill cannot make consistently good products, at a profit, without the installation of an air-conditioning plant. During recent years, however, the woollen industry has applied air conditioning to their industry with decided advantages, namely, that static electricity is prevented, and better quality roping. (Roping is the rope-like material of wool fibres before it is twisted into yarn.) In the artificial-silk industry air conditioning is very important, due to the process of manufacture being more of a chemical one than a mechanical one. In the preliminary processes of manufacture a variation of temperature means considerable loss through spoilt material. In the spinning, twisting and reeling processes it is necessary to have a very high degree of humidity. The lustre produced on the finished material depends very largely on the amount of moisture contained in the atmosphere.

The advantages in general to the textile industry of air conditioning are as follows :—

Greater production, higher and more uniform quality, fewer seconds less waste, greater strength, better wear, superior finish, lower production costs, the generation of fly and dust are prevented. The strength of the fibres is increased, due to the natural gums in the material being kept in the correct state for working. Healthy workers making greater production.

The Printing Industry.

Let us first consider that very important material used in printing, paper. The best percentage of relative humidity for paper is 60 per cent. At this percentage of relative humidity paper will contain from 5 to 7 per cent. of moisture, the variation being that the raw fibres used in the manufacture of paper do not all take on exactly the same percentage of moisture at a given humidity percentage. Paper which does not contain from 5 to 7 per cent. of moisture is not in prime condition, and lithographers and printers should insist that the paper they buy reaches them with this moisture content. The production of printing at minimum cost and maximum output is possible only when the stock is constantly in prime condition. Paper in stacks will not immediately condition itself to the humidity conditions of the room, and if it is necessary to use paper within a few hours of its receipt, it should be racked in layers of about fifty sheets, or hung up in hangers. When treated in this way the paper will condition itself in a few hours, the actual time depending, of course, on the number of sheets and on the quality of the paper. It is necessary to have the air-conditioning plant under automatic control for printing, because when doing two-colour work any variation in the humidity would cause variation in the size of sheet, and the work would be spoilt. The advantages of air conditioning to the printing industry are as follows :—

The elimination of static electricity, by making it impossible for the paper to retain the static charge. The elimination of variations in size of sheets. The elimination of all the troubles in the operation of automatic sheet feeds which are caused by static electricity. The elimination of curling and wavy edges in stock, which is caused by variation in the percentage of relative humidity. The elimination of spoilt work and lost time in operation of folding machines. The elimination of wrinkling on offset presses, which is due to curled and wavy stock. Rollers work better and last longer. Their diameter remains constant, and therefore the time lost in setting them is saved. Ink runs better and dries uniformly. There is greater affinity between paper and ink. The pressman always knows how long work must stand before the sheets can be backed up, or be handled by the bindery. Sheets can be folded with a minimum amount of cracking at the fold due to the fibres and the coating being kept pliable.

Another important item is the prevention of loss of ink due to evaporation, and with a properly designed air-conditioning plant installed a considerable saving can be effected.

Bakeries.

In bakeries there is a considerable amount of heat generated from the ovens, this reduces the relative humidity of the air, and it is necessary to instal air-conditioning plant to prevent the crusting of the dough during fermentation. The correct relative humidity for a bakery is 75 per cent. Flour, that very necessary ingredient of bread, is very susceptible to moisture, and for this reason it is usually stored in a cool dry room. The rate of fermentation of the dough is dependent on the atmospheric condition of the air, and the hardened crust is due to the evaporation of moisture from the surface of the dough. The more rapid the evaporation the heavier the crust forms. Correct control of the humidity prevents crusting. If crust forms fermentation is retarded because the dough is prevented from rising to the fullest extent, the gluten is not properly stretched and developed and the volume of the loaf is lessened. It is wise to instal air-conditioning plant in the despatch room of a bakery, because bread will soon go stale if stored in a dry room. The plant installed should be of a flexible nature, and able to cater for the different classes of bread being produced.

Tobacco

When the tobacco leaf is picked it contains anything from 60 to 80 per cent. of moisture. The curling of the tobacco is done by the removal of this moisture, and the rate at which the moisture is evaporated, and the method used decides the quality of the tobacco. Until recently tobacco was cured by having the leaves hung in drying sheds, the drying taking place by natural means. This had obvious disadvantages due to large fluctuations in temperature and humidity. With an air-conditioning plant it is, of course, possible to control the rate of evaporation. There are three distinct stages in the curing of tobacco leaf, and it will be seen that it is necessary for the air-conditioning plant installed to be able to give conditions within a large range. The first stage is yellowing the leaf; during this process the temperature is kept at the normal atmospheric temperature, then it is increased to about 95° F. The reason for keeping the temperature low in the first stages is that a high temperature would kill the leaf before it had changed from the original green to a yellow colour. The temperature of 95° F. is maintained until the leaf begins to turn a yellow colour, the temperature is then increased to 100° F. until the leaf turns dark yellow. When the leaf shows a distinct dark yellow the temperature is increased to 115° F. until the leaf is finally cured. During this process the amount of moisture contained in the air must be such that the leaf is prevented from drying too rapidly. It is usual to have a wet-bulb depression of 3° F. The whole process of curing takes about sixteen days. In the stock rooms the humidity must be kept constant and be under automatic control, as any excess in moisture would cover the leaf with condensation and mildew would form; on the other hand if the air is too dry the leaves would wither. The correct conditions for the stock rooms are 60° F. with 66 per cent. relative humidity.

In the twist room it is necessary to keep the tobacco in a pliable condition. If the tobacco is too dry it will not allow itself to be twisted and the leaf will crack and fall away. This also applies to cigar manufacture. As tobacco is mostly sold by weight it is advisable to have an air-conditioning plant installed in the warehouse for the following reason, if the tobacco leaves the factory with a fairly high moisture content, and it is stored in a dry warehouse, there will be a considerable loss in weight due to evaporation of the moisture from the tobacco. This may amount to a considerable financial loss in twelve months' time.

General Design

It will be as well to give a rough indication on what lines air-conditioning plant should be designed for the above industries, as obviously one cannot lay down any hard and fast rules because every installation becomes an independent problem.

In the textile trade, power is not a very important factor as usually most mills have existing driving shafts which carry a good margin of power, and it is possible to drive off these. Noise is also of secondary consideration, and therefore fairly high velocities are permissible in the system. Steam is usually available from the existing boilers. Rectangular ducts should be avoided wherever possible as they collect dust, and are not as efficient as circular ducts. In the printing industry the above principles hold good, while for bakeries noise should be considered, although it is not of vital importance.

In the tobacco industry ducts should if possible be constructed of copper sheets, spray nozzles of manganese bronze, air-washer and eliminator plates of copper sheets and copper for all pipework. Air quantity should be calculated on the summer requirements. In textile mills it is usual to fit an air filter before the air washer to prevent any fog being drawn into the room. A filter of the cloth type is the best, because while a viscous filter will certainly collect dust it is not suitable for fog filtration.

Building Research Station, Garston, Nr. Watford, Herts.

THE KATA-THERMOMETER AS LESLIE'S ANEMOMETER AND A SIMPLIFIED METHOD FOR COMPUTING

By A. F. DUFTON, M.A., D.I.C.

In the opening sentence of a recent paper[1] Sir Leonard Hill stresses the fact that practical experience has shown that one of the greatest uses of the kata-thermometer is as an anemometer. Such an anemometer was, indeed, described 130 years ago by John Leslie,[2] who suggested that the rate of cooling of a thermometer should be used for measuring the velocity of the wind and specified that "The bulb of the thermometer ought to be more than half an inch in diameter, and may, for the sake of portability, be filled with alcohol, tinged, as usual, with archil."

Leslie did not measure the time of cooling over a fixed interval of temperature. He first held the thermometer in the air and marked the temperature: the thermometer was then warmed by the application of the hand and the time noted which it took to sink back to the middle point when the bulb was exposed to the impression of the wind ; from this the velocity of the wind was deduced by an easy rule. To simplify the observation, Leslie proposed that a sliding scale of equal parts should be applied to the tube and he also suggested that extemporaneous calculation might be avoided by having a table engraved upon this scale relating the velocity of the wind to the time of cooling.

---

[1] T. C. Angus, Leonard Hill and H. E. Soper, *Journal of Industrial Hygiene*, 1930, Vol. 12, p. 66.

[2] John Leslie, " An Experimental Inquiry into the Nature and Propagation of Heat," London 1804.

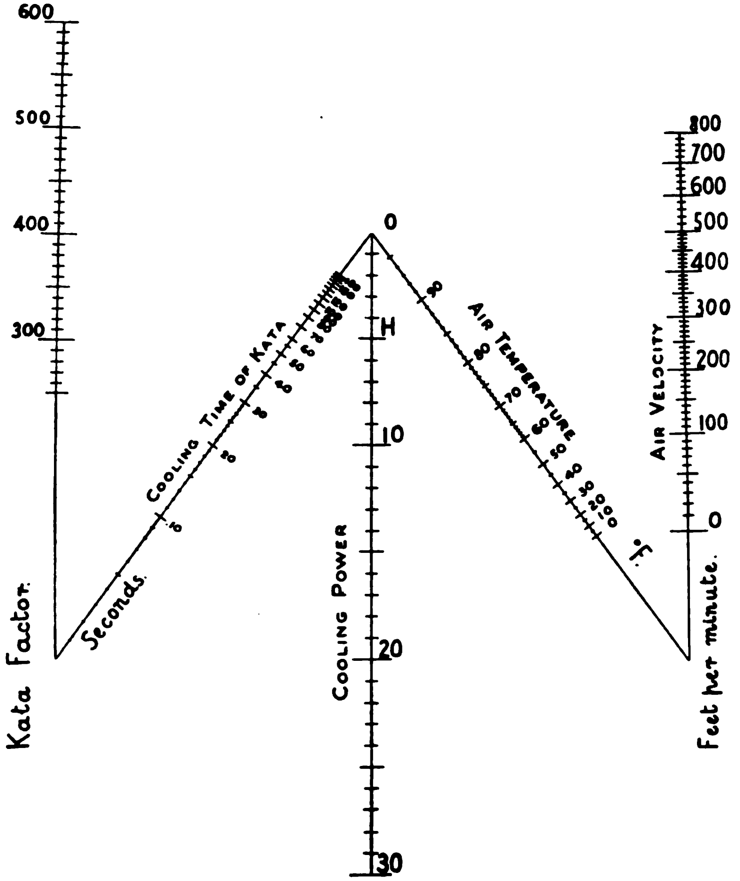


FIG. 1.

Leslie's anemometer fell into desuetude and it has only achieved popularity since a suitable thermometer for the purpose has become generally available in the kata-thermometer, the instrument designed by Hill as an indicator to determine whether a room is too hot or too cold, too stuffy or too draughty.

Leslie's "easy rule" is not sufficiently accurate for modern requirements and Hill and his associates have devoted considerable time to the study of the effect of air movement upon the cooling of the kata-thermometer. Their most recent work gives the velocity in feet per minute as

$$197\left\{8\,\frac{F - 0.15\,(97{\cdot}5 - T)\,t}{1.85\,(97{\cdot}5 - T)\,t - F}\right\}^{\frac{5}{4}}$$

where *F* is the factor of the kata-thermometer, *t* the time of cooling in seconds and *T* the air temperature in degrees Fahrenheit. This formula is difficult to calculate from and, to facilitate computation, Angus, Hill and Soper have suggested the use of the alignment chart shown in Fig. 1.[3]

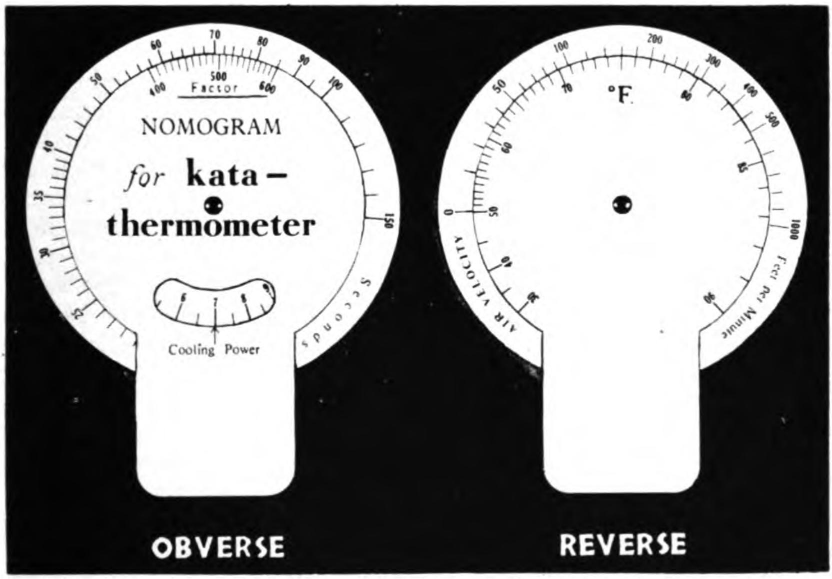


FIG. 2.

This chart is not very convenient and the nomogram illustrated in Fig. 2, which is based upon the same formula, is now put forward. When the cooling time in seconds is set to the appropriate factor for the kata-thermometer, the air velocity is read directly against the air temperature on the reverse of the nomogram ; the cooling power, if required, is shown by the arrow.

---

[3] *Loc. cit.*

NEW BOOKS

HEATING AND VENTILATION

Heating and ventilating engineers being concerned mainly with the practical side of their work sometimes fail to keep abreast with the principles and new theories which are the foundations of progress. Dr. H. M. Vernon, formerly investigator for the Industrial Health Research Board, having found that in text-books the practical applications necessitate so much detailed information that they are apt to treat in a very cursory fashion the theories on which the subject is based, has produced a useful book* describing the principles of heating and ventilation. Chapter 1 deals with the environmental conditions controlling the heat loss from the human body, dry-bulb temperature of the air, air movement and cooling power and the practical application of the kata-thermometer. The effects of clothing and radiant heat are considered and reference made to the eupatheoscope and globe thermometer. Chapter 2, on heat loss from buildings discusses factors concerned in heat transmission, coefficients, the effects of wind and infiltration. Dealing with the reduction of heat losses, the author doubts whether it is wise to reduce infiltration too much, owing to the possible reduction of ventilation. The latest consideration in connection with heat losses from buildings is that of solar radiation effects which are briefly discussed. Dealing with heating by means of open fires, in Chapter 3, the author discusses coal fires, gas and electric fires, anthracite stoves, coke fires and stoves and the relative costs of various methods. Chapter 4, on systems of heating by hot water and steam radiators, refers to the principles on which the systems are designed. The term " drop riser " used in connection with the overhead system, seems to be rather unfortunate. Also the statement that hot water being lighter than cold water, it tends to rise and thereby induces a circulating pressure and again warm air ascends whilst cool air is sucked in, are common errors. Actually, the circulation is due to the hot body cooling, increasing in density and forcing the lighter body upwards. Chapter 5, on low-temperature radiant heating, discusses the panel system, its radiation and economies claimed, under-floor heating is also discussed. Low-temperature heating by electricity is the title of Chapter 6 and discusses embedded and non-embedded panel systems and cost, thermal storage, tubular heaters and small medium-temperature heaters. The next three chapters deal respectively with the necessity for ventilation, natural ventilation, mechanical ventilation and warm air heating. Since Sir Leonard Hill's experiments on the effects of carbon dioxide, ventilating engineers have ceased to consider the parts of CO_2 per 10,000 for the standard of ventilation and now only use the CO_2 measurement of the content as a means of testing the air distribution. The more important considerations being air movement, micro-organisms, dust and humidity. The author briefly discusses the question of the influence on the ionization of the air. When dealing with types of fans the author should have referred to the report of the Institution's Fan Standardisation Committee for his definitions. The important subject of humidity control is dealt with in Chapter 10. The final chapter deals with air conditioning and special ventilation in industry which is becoming a very important branch of the heating and ventilating industry, not only in relation to the health of the operatives, but also for industrial processes. One of the first thoughts that arise after reading this book is the care the author has devoted to giving the numerous references to the sources of much of his information in the hope that his book will be read in conjunction with the text-books quoted. The author has produced a very readable book dealing with the principles of the subject, including the most recent theories and should be read by all who require information regarding the standards of heating and ventilating for buildings.

---

* " Principles of Heating and Ventilation." By H. M. Vernon. 9½ in. by 6 in, 232 pages. 52 illustrations. Cloth. Published by Edward Arnold & Co., London. 1934. Price 14s. net.

A.S.H.V.E. GUIDE, 1934

The American Society of Heating and Ventilating Engineers in the twelfth edition of their Guide* has considerably enlarged and revised the technical data section which is devoted to every subject in connection with heating, ventilating and air conditioning practice. The 42 chapters have been arranged for convenient reference and contain a vast amount of information from the practical experience of members as well as from available research sources. The whole of the data in the previous edition have been reviewed. Some of of the chapters have been revised and amplified, while others have been completely replaced. The new chapters include the cooling load and cooling methods, air conditioners, radiant and electric heating, humidifying and dehumidifying equipment, steam heating systems and piping. The tables of pipe sizes for steam systems have been presented in more compact and simplified form. Extensive changes will be noted in the chapters on industrial air conditioning, natural ventilation, central fan systems, air-cleaning equipment, sound control, mechanical furnace systems, radiators and gravity convectors, heating boilers, pipe insulation, pipe, fittings and welding, definitions and terms. The remaining chapters were revised in order to bring them up to date. Slight modifications have been made in the chapters on heat transmission and air filtration based on a careful check of the experimental work which produced the basic figures. The method of application in practice, however, has been slightly modified in this edition. With the 42 chapters and a comprehensive index to the text which occupies 618 pages, the Guide 1934 presents the largest technical data section ever compiled and published by the Society. The Catalogue Section consisting of 176 pages, gives supplemental engineering data of 108 leading American firms. The Guide was prepared under the direction of the Guide Publication Committee, consisting of W. L. Fleisher, Chairman, D. S. Boyden, F. E. Giesecke, S. R. Perry West, and about fifty others who co-operated in its preparation, reviewing and editing the text. The membership section comprises 56 pages. The text was prepared for and will be invaluable to engineers, architects, contractors and students who are designing, operating, specifying, installing and studying systems and apparatus, the functions of which are to create comfort and to improve the efficiency of processing.

---

* "American Society of Heating and Ventilating Engineers' Guide, 1934." 6 in. by 9 in. 862 + 56 pages. Illustrated. Flexible leather. Published by A.S.H.V.E., New York, U.S.A., 1934. Price $5.

HOT-WATER SUPPLY

Many faults and failures occur in domestic hot-water supply apparatus in houses owing to the fact that they are not installed by heating engineers. The users do not understand why these troubles arise and often blame the system when they should blame the person who did the work. Mr. Watson, in this little book,* written more particularly for the general householder, explains in simple language the reason for the various faults and failures. In his foreword he states that it is not intended to be a text-book for the professional man, but just a simple explanation of hot-water supply for the home. The book opens with an explanation of hot water and how it circulates by gravity. The various components of hot-water apparatus and their use are clearly described and illustrated in colours. What constitutes a satisfactory hot-water supply is next dealt with and an explanation of a properly proportioned apparatus. The causes of a number of faults and failures are then described, showing why they occur and how they may be remedied by means of a patent fitting, the sale of which is doubtless the principal reason why the book was written. Although not intended as a text-book for the professional man, Mr. Watson has written an interesting book which should be understood by the user of domestic hot-water supply and at the same time will be found useful to students dealing with its design and the hot-water fitter who installs the apparatus.

---

* "Hot-Water Supply in the Home." By A. R. Watson. 5 in. by 7½ in. 63 pages. 27 coloured plates. Published by E. & F. N. Spon Ltd., London, 1934. Price 2s. 6d.

ABSTRACTS

Air for Comfort Cooling. 697.9

Experience with comfort cooling work has demonstrated that it is generally unsafe to try to introduce air into an occupied apartment at a temperature of less than 10 to 15 degrees Fahrenheit below the temperature maintained in the room. However, it may be assumed that if the outlets are properly spaced and located, so that the air is thoroughly diffused before striking an occupant, 15 degrees lower temperature may be employed.

The amount of heat that the air will pick up after entering the room is, roughly, 1/55 B.T.U. for each cubic foot for each degree rise in the air. Consequently, if the air rises 15 degrees after entrance, it will pick up 1/55 B.T.U. × 15, or 3/11 B.T.U., and this figure is generally taken as a quarter of a B.T.U. Therefore, it will require four times as much air per *hour* as there are B.T.U. to be removed.

The cubic feet per minute will be 1/60 of the cubic feet per hour, or 4/60, which is 1/15 of the B.T.U. per hour to be removed. With 10,000 B.T.U. per hour to be removed, the air required when entering at 15 degrees below the room temperature will be 10,000 × 1/15, or 667 c.f.m.

Suppose, however, that the air is not well distributed and is not desired to enter at more than 10 degrees below the room temperature. Then the ratio becomes 1/15 × 10, or 2/11 B.T.U. removed by each cubic foot, so it will take 1 B.T.U. ÷ 2/11, or 5½ cubic feet of air for every B.T.U. removed. Then the c.f.m. will be 5½ ÷ 60, or 0.091 c.f.m., and under this condition the removal of the same 10,000 B.T.U. per hour given above will require an air supply of 10,000 × 0.091, or 910 c.f.m.

Thus it will be seen that the quantity of heat to be supplied depends upon (a) the amount of heat to be removed, and (b) the difference between the room temperature and that of the entering air.

A certain amount of outside air is always needed in air-conditioning systems, this being determined by the minimum amount which must be used to avoid the accumulation of unpleasant odours. Experience has shown this to be about 25 per cent. of the total supply, although with ionizing it is claimed that as high as 90 per cent. recirculated air may be used without objectionable odours. (Harold L. Alt. *Plumbing and Heating Trade Journal*, March 1934.)

Air Infiltration. 622.416

Stress is often laid on the value of a flued fire in creating a circulation of air for purposes of ventilation. This point can be over-emphasised, for in the modern house there is usually ample infiltration of air through windows and doors to maintain healthy conditions, unless the heating appliances are themselves consuming oxygen and discharging fumes into the room.

Carbon monoxide and oxide of nitrogen (which can result from the imperfect combustion of gas) are admittedly dangerous. One part of either of these gases to 10,000 parts of air is objectionable, and 5 to 10,000 dangerous. Carbon dioxide, on the other hand, is relatively innocuous, and the frequently quoted maximum permissible : 10 parts of CO_2 to 10,000 parts of air, can usually be greatly exceeded without distress. According to Professor Sir Leonard Hill, M.B., F.R.S., 500 CO_2 to 1,000 air is tolerable under certain conditions. Without, however, anticipating or approving such concentration, it must be admitted that the CO_2 content of a room's atmosphere may vary within relatively wide limits. Much more dangerous to health is dust of any nature.

The rate at which heat is dissipated from a room is not usually under the control of the heating engineer, as it is related to the exterior temperature, the nature of the walls, floor and ceiling, and air currents which are admitted. It must, however, be considered in choosing a heating system, for a room which chills rapidly is best heated by means which do not demand a constant flow of air up a flue and a corresponding inflow through doors and window crevices.

Associated with this question are adjacent spaces to which the room opens, and their relative heat. (Alexander H. Hayes. *The Architects' Journal*, March 22nd, 1934.)

Mental Effort Produces No Heat. 622.416

An elaborate series of studies, recently completed at the Carnegie Institution, Washington, D.C., has revealed that mental effort is without significant influence upon the energy metabolism of the human body. In a practical sense, the investigations showed that the production of heat energy within the body by the oxidation of food is not materially increased by the accomplishment of mental work, as it is by physical effort.

For the tests six men and one woman, all university-trained, were selected as subjects, and the simple basal metabolism apparatus, in somewhat modified form, was used to determine oxygen consumption and carbon dioxide exhaust. The subjects, wearing light, comfortable helmets, fitting the neck so closely that no air could leak in or out, concentrated on mental arithmetic problems while reclining at rest.

The mental gymnastics produced a slightly more rapid pulse and an increased rate of respiration which resulted in an increase of oxygen consumption of 4 per cent. over the normal consumption when the mind and body are both at rest. The functioning of the brain, in itself, had nothing to do with the increased rate of oxidation within the body. So far as heat production is concerned, the metabolism of the average individual is increased by 9 per cent. over the basal, as compared with the 3 or 4 per cent. resulting from brain work. Such light feminine tasks as sewing increase the rate by 13 per cent., and sweeping and dusting result in a metabolism rate that is 140 per cent. of the basal.

The studies were made by Dr. F. G. Benedict collaborating with Mrs. Benedict. (*Heating and Ventilating*, March 1934.)

Mechanical Stokers. 621.183.6

There are now on the market several mechanical stokers, some of which are suitable to be fitted to boilers of certain standard types and design. One, for example, consists of a screw conveyor which delivers the broken coal up into the fire from below and works very successfully on certain types of fuel. With such a stoker, all that is necessary is to fill a hopper twice a day and at the same time remove any ashes and clinkers.

This type is generally employed in conjunction with forced draught, which also enables a coal costing about 23s. per ton in London to be used in places where, without such draught, a fuel costing 35s. or thereabouts is otherwise necessary. This economy obtained with forced draught can, of course, also be obtained without adopting the mechanical stoker.

On larger boilers there are, of course, other types of well-known mechanical stokers which are generally specially suitable to a particular type of boiler.

The screw-conveyor type of mechanical stoker is, however, not always very suitable to take coke, owing to the excessive friction of the latter. This problem has recently received a great deal of attention, with the result that magazine boilers have been evolved which will burn coke successfully and which contain a sufficient supply to work for 12 or even 24 hours without refilling.

One of the difficulties to be overcome is that the grate area of most existing coke boilers is so small that the rated heat output of the boiler can only be maintained with an exceedingly high temperature of fuel on the grate.

With many types of fuel, including most cokes and many coals, this inevitably leads to clinkering, which is sufficient to prevent the use of such a boiler for long periods without attention. Hence, magazine boilers intended to go long periods without attention must be designed for a much larger grate area for a given rated capacity. These boilers are therefore necessarily somewhat more expensive, but if the interest and depreciation on the additional cost comes to something much less than the £150 per annum required for additional attendance, the net result is, of course, a saving to the building owner. (Oscar Faber. *Building*, March 1934.)

The Wet-Bulb Thermometer. 533·3

There are a number of reasons for retaining the wet-bulb thermometer as the most practical indicating instrument in air-conditioning work. There is no doubt, however, that considerable improvements in design and mode of use will be necessary before its indications can be used to give the moisture content of air with precision.

The abundant experimental work carried out to date, combined with the analyses of the mode of functioning of the device, have brought out clearly the complex inter-relations of various factors. To begin with, the wet-bulb temperature is very much a function of the velocity of the air streaming past the bulb. The effects of radiation can moreover by no means be neglected, although the apparatus can be designed in such a way as to annul this effect. The temperature effects of the impinging air on the thermometer are likewise not to be neglected.* Also, water has a limit to its rate of evaporation and at higher air velocities an effect, while not thus far demonstrated, may enter significantly and affect the readings.

Up to the present time the moisture content of air has been deduced from the wet-bulb readings by the use of a formula which cannot be strictly justified or considered complete. In the first place, the analysis has been directed to a form of apparatus which has not been specifically designed to nullify or eliminate those factors which are especially difficult to include in the analysis. In the second place, even granting that the analysis is complete, and it is far from being so, the physical constants involved, such as heat conduction coefficients, diffusion coefficients, emission and absorption coefficients, etc., are not known with the precision necessary to enable moisture content to be computed satisfactorily. Finally, it should be noted that the usual scientific procedure is to make theory fit the facts, whereas the situation in the field of psychrometry has savoured of a reversal of this logical procedure with attendant confusion.

There seems to the authors no escape from the conclusion that two steps are required before a definitive psychrometric table (and chart) can be prepared. First, the wet-bulb thermometer should be developed to the point where it is radiation shielded and generally reduced to a design which will give reproducible readings to 0.01° C. This is not an impossibility in a commercial instrument. Second, given a really sensitive and reliable wet-bulb instrument, the actual analysis of air as a function of the wet-bulb indications should be carried out at different temperatures, using test air of varying moisture content. The velocity effect would appear to be secondary in the second phase of the investigation, for the first step of developing a satisfactory precision instrument would involve a study of this factor. (Frederick G. Keyes and Leighton B. Smith, *Refrigerating Engineering*, March 1934.)

---

* See for example Joule's Scientific Papers II, p. 321. Joule measured the temperature effects arising from air rushing past objects having surfaces of different roughness and character. His findings make clear that the smooth bulb of a thermometer would be affected differently than the bulb covered with material, as with the wet- and dry-bulbs in psychrometry.

Combustion Efficiency of Oil. 621.182.23

The conditions of combustion may be ascertained by the analysis of the flue gas, that is by recording the percentage of CO_2. Perfect combustion of petroleum oil is represented by a theoretical figure of about 15 per cent. CO_2. However, it is not desirable to attempt such a high result even if it were practicable, but 13½ per cent. to 14 per cent. would be excellent if attainable.

Generally speaking, 12 per cent. CO_2 is considered very satisfactory for the larger boilers rated from one to two-and-a-half millions B.T.U., while for the smaller boilers, 8 per cent. to 10 per cent. would probably be the best result obtainable.

These remarks apply to the average design of sectional boiler and not to the specially constructed boilers for oil-firing, which should reasonably be expected to give the best results.

Combustion efficiency will vary between 65 per cent. and 95 per cent., but for the general purpose of estimating oil consumption, 80 per cent. should be taken as an average.

Thus an oil having a calorific value of 19,200 B.T.U. per lb. would have an input value of about 135,000 B.T.U. per gall.

The amount of heat absorbed from this input is now dependent on the design of the boiler and the extent of the heating surface.

Small boilers lacking in flue travel have poor efficiency, i.e., about 50 per cent., while large, well-designed boilers will give 75 per cent. efficiency, intermediate sizes ranging from 300,000 to 1,000,000 B.T.U. will have efficiencies from 60 per cent. to 70 per cent. (*Heating and Ventilating Engineer*, February 1934.)

HEATING AND VENTILATING INDEX

Psychrometry. 551·57

The Mollier Psychrometric Chart. Ferdinand Keppler. 3¼ pp., 2 illus. Illustrating and explaining the development of the chart for the English system : *Refrigerating Engineer*, February 1934.

Heat Insulation. 621.185.6

Metal Heat Insulation. Joseph Le Grand. 2½ pp., 3 illus. Survey of developments in the field of metal heat insulation : *Refrigerating Engineer*, February 1934.

Calorifiers. 697

Les Appareils Echangeurs de Température dits : " Rechauffeurs à Contre-courant." R. Chassereau. 4 pp., 5 illus. Dealing with the application and calculation of calorifiers with counter-current using steam to heat the water : *La Couverture-Plomberie*, February 1934.

Drying. 634.9

Principles of Drying. C. W. Ulett. 4 pp. Dealing with application of heat in drying, methods ; natural, mechanical, indirect heating : *Heating and Ventilating Engineer*, February 1934.

Oil Burners. 621.182.23

Automatic Oil Burner Installations. 2½ pp. Dealing with calculating oil consumption : *Heating and Ventilating Engineer*, February 1934.

Heat Transmission. 536.2

Heat Losses. Leslie Rayner. 2¼ pp., 2 illus. Explaining how the B.T.U. heat loss is overcome, in what form and how distributed : *The Plumber*, March 1st, 1934.

Heat Conductivity. 536.2

Recherches sur la Protection Calorifique avec les Procédés Nouveaux de Construction des Murs. I. S. Cammerer. 8 pp., 8 illus. Researches on the establishment of a new basis for calculating coefficients of heat conductivity of building materials according to their specific density and humidity content : *Chauffage-Ventilation*, February 1934.

Psychrometry. 533·3

The Present State of Psychrometric Data. Frederick G. Keyes and Leighton B. Smith. 3½ pp., 1 illus. Dealing with use of ideal gas laws, wet-bulb thermometer and psychrometry below the ice point : *Refrigerating Engineering*, March 1934.

Sound Insulation. 534

Acoustics. C. W. Glover. 4 pp., 5 illus. Study of modern methods of sound insulation and points to be observed : *Building*, March 1934.

Building Equipment. 697

Services. Oscar Faber. 2 pp., 1 illus. Dealing with heating, ventilation, lifts and water supply : *Building*, March 1934.

Air Conditioning. 697.96

The Origins of Air Conditioning. David L. Fiske. 5 pp., 10 illus. Early history of ventilation and air conditioning : *Refrigerating Engineering*, March 1934.

Psychrometry. 533·3

The Mollier Psychrometric Chart. Ferdinand Keppler. 4 pp., 5 illus. Explaining practical examples of use : *Refrigerating Engineering*, March 1934.

Oil Burners. 621.182.23

How to Instal Oil Burners under Gas Designed Boilers. C. W. Whitney. 3½ pp., 4 illus. Dealing with requirements necessary when heating installations designed for gas are converted to burn oil : *Domestic Engineering*, March 1934.

Ventilation. 697.9

Attic Ventilation. G. B. Helmrich and G. H. Tuttle. 6 pp., 8 illus. Describing investigation on comfort cooling by use of exhaust fans : *Domestic Engineering*, March 1934.

Automatic Heating Equipment. 697

How to Select Boilers for Automatic Oil, Gas and Coal Jobs. H. L. Alt. 4 pp., 7 illus. Discussing calculations necessary when boilers are adapted for use with automatic heating equipment : *Domestic Engineering*, March 1934.

Pulverised Fuel. 662.87

Design of Burners for Pulverised Fuel. 6½ pp., 4 illus. Dealing with principles of burner design, ignition and combustion, flame propagation, burner design and secondary air : *The Fuel Economist*, March, 1934.

Heating. 697

Modern Heating Systems. Alexander H. Hayes. 10 pp., 13 illus. Dealing with fuel cost, radiated and convected heat, cost of plant and heating by electricity, gas, hot water, steam and pipeless heating, automatic control of electricity and fuels : *The Architects' Journal*, March 22nd, 1934.

Humidity. 533·3

Humidity Measurements in Freezer Rooms. Arthur W. Ewell. 1½ pp. Dealing with humidities at low temperatures in connection with cold storage : *Refrigerating Engineering*, March 1934.

Waste Heat. 621.181.62

Waste Heat from I.C. Engines. 5½ pp., 7 illus. Reviewing question of waste heat and showing how 30 per cent. of heat is lost in jackets and exhaust gases and 10 per cent. are recoverable in waste heat boiler : *The Fuel Economist*, March 1934.

Refrigeration. 621.565

New Development in Water Vapour Refrigeration. Paul Boncel. 3½ pp., 3 illus. Discussing problem of using water as a refrigerant in which a power-driven compressor takes the place of the steam jet : *Heating and Ventilating*, March 1934.

Motors. 621.313

Selecting Motors for Heating and Air Conditioning Equipment. L. Gwathmey and B. S. Weaver. 2 pp., 1 illus. Dealing with motors for fans, refrigerating compressors, oil burners, stokers and pumps : *Heating and Ventilating*, March 1934.

Air Conditioning. 697.96

Treating and Handling Outside Air for Effective Air Conditioning. Harold L. Alt. 2½ pp., 2 illus. Dealing with amount of outside air required, quantity to be recirculated and methods of cooling and dehumidifying : *Plumbing and Heating Trade Journal*, March 1934.

Ventilation. 697.9

Recent Developments in the Ventilation of Buildings. A. T. Henly. 2½ pp., 2 illus. Dealing with natural ventilation, air conditioning, control, cooling and acoustic problems : *The Architects' Journal*, March 22nd, 1934.

Corrosion. 621.196.5

Corrosion Studies in Steam Heating Systems. R. R. Seeber, F.A. Rohrman and G. E. Smedberg. 3 pp., 4 illus. Describing research on relationship of oxygen, carbon dioxide, pH value and method of operation : *Heating, Piping and Air Conditioning*, March 1934.

Air. 533·3

Thermodynamic Properties of Moist Air. John A. Goff. 7 pp. Dealing thermodynamically with the properties of atmospheric air based on best available thermal data : *Heating, Piping and Air Conditioning*, March 1934.

NATURAL VENTILATION

By F. S. CAINK (Associate Member)

ASSOCIATE MEMBERS AND GRADUATES SECTION

LIVERPOOL, FEBRUARY 9th, 1934

Introduction.

THE objects of this paper are (1) to set out the case for natural ventilation, which will involve its comparison with mechanical ventilation and the respective efficacy of the two systems to produce ideal ventilation, having first elucidated the object of ventilation.

(2) To explain the features and performance required of a ventilator to make it efficacious and thereby to determine a criterion or standard by which such ventilators may be judged. Such a criterion is sorely needed.

For instance, a manufacturer will place a ventilator on the market having a certain outstanding characteristic. The characteristic may have no bearing on the article's ability to ventilate, though in such a case the manufacturers will invariably claim it to be of paramount importance.

With numerous concerns each expounding a different principle of ventilation, for obvious commercial reasons, the public may well wonder whether there is really any virtue in natural ventilation or whether it is just a commercial ramp.

I shall outline some of the more important factors to be observed in applying natural ventilation, and the performances that may be obtained with such systems.

The chemical and psychological aspects of ventilation in general will not be discussed, as this has been dealt with very adequately by R. C. Frederick in his papers on "Ventilation Conditions,"* also by Sir Leonard Hill and other eminent authorities on the subject.

The information given in this paper regarding natural ventilation has been obtained or confirmed by practical experience under working conditions, and laboratory research.

Many will assert that a laboratory test of a natural ventilator is no criterion of its efficacy, as all the natural conditions cannot be reproduced accurately at one time.

But such tests are obviously suitable for comparing the performance of various types of ventilating devices, and it has been found by checking the results with those obtained under working conditions that all the more significant open-air conditions can be reproduced in the laboratory with a fair degree of accuracy.

---

* Inst. of Chemistry, London, March, 1929.

Necessity for Ventilation.

Ventilation may be divided roughly into two classes.

(1) The production of comfortable atmospheric conditions in a building, and the removal of stale air vitiated by the occupants.

(2) The removal of heat, moisture, or fumes produced from sources other than the occupants.

The necessity for the former class of ventilation is brought about by the fact that the human machine has been evolved to function within the range of atmospheric conditions that exist in the open air. The conditions obtaining in an unventilated building do not come within this range, and the health, mentality and energy of the occupants suffer in proportion to the discrepancy.

There is a popular saying that we can live three weeks without food, three days without water, and three minutes without air. Like most popular sayings this is not strictly accurate, but it illustrates the relative importance of air in maintaining life.

Air, like food and water, must be present in a suitable condition for the body to function efficiently. The exhilaration experienced on passing into fresh air from a stuffy room clearly indicates the enervating effect of bad ventilation.

Civilisation causes many of us to live in uncomfortable and unhealthy atmospheric conditions, but it also enables us to accumulate sufficient knowledge to combat those conditions.

Unfortunately there is always a time-lag between the imposition of civilisation's burdens and their relief by man's ingenuity.

This lag is represented by the time taken, firstly to recognise a new artificial condition as being unhealthy, secondly to discover the reasons for it, thirdly to devise a remedy, and finally, but by no means least, to persuade the general public that a remedy is necessary, for people are very adaptable to environment and frequently do not realise that they are jeopardising their health, and that improvements can be made by reducing the difference between their artificial conditions and those that they would encounter were they living in an ideal natural state.

I suppose we are about half-way through the time-lag in the rectification of bad air conditions in buildings, in that we have recognised their evil and have devised certain remedies, but, broadly speaking, we are not yet out of the experimental stage, and have a great deal to learn about the physiological, psychological and mechanical aspects of ventilation.

It is the object of ventilating engineers to reproduce as faithfully as possible ideal open-air conditions inside a building.

By ideal, I mean the type of outside conditions that would be most suitable for the occupants, in view of their occupation, attire and general physical condition. They should feel the air to be cool rather than warm, dry rather than damp, slightly varying in temperature in different parts and at different times rather than uniform and monotonous, gently moving rather than still, and finally free from annoying odours and floating matter.

Methods of Producing Ventilation.

Now how has this problem been tackled to date?

The most primitive method of ventilating a building was to leave holes in the walls for the admission and exit of air.

Then it was discovered that one hole in the roof and one in the wall near floor-level would cause air to flow through a warm building, even when there was no wind. This fact must have been very evident to the people who used a simple hole in the roof in place of the more recent chimney to allow the smoke from their fires to escape, and it was probably noticed that more air passed through the room when a fire was burning. This would indicate to an intelligent observer that the air was rising to the top aperture on becoming warmed. Such an observer would also note that still more ventilation was effected when a wind was blowing across the hole in the roof.*

These two phenomena are the basis of what we know as natural ventilation.

But the hole in the roof was inconvenient in bad weather and chimneys were built down to a foot or so above the fire, and although this dealt more adequately with the smoke, the general ventilation suffered, as the warm stale air above the chimney opening became pocketed.

However, for dwelling-houses a partially opened window is still considered to provide sufficient ventilation.

But in such buildings as assembly-rooms and factories something more than this is required, and mechanical devices have been employed for producing a flow of air through a building, and for this purpose the fan in its various forms is now universal in the sphere of mechanical ventilation.

Steam blowers have been used in the past to induce a flow of air for certain industrial purposes, but have died a natural death owing to their inefficiency.

Mechanical Ventilation.

Now let us consider the features of mechanical ventilation. Does such a system reproduce natural conditions? I think not!

Air is drawn from or blown in at one or more points at a velocity very much in excess of that of the general movement of the atmosphere in the building. This means draughts, and is usually a source of discomfort or ill-health to the occupants. In an effort to obviate draughts plenum systems are frequently used, but the air must still enter at a comparatively high velocity, although draughts entering from the outside are reduced owing to the super-atmospheric pressure maintained in the building, but this excess of pressure is small, and is not great enough to keep out draughts that would enter when a strong wind is blowing.

---

* Provided its edges are raised above the level of the roof.

Fan ventilation is essentially constant and monotonous, which is not a natural condition.

It is frequently noisy, it requires a power-supply, which means running costs, and the upkeep costs are by no means negligible, especially when corrosive fumes or even steam is to be exhausted. In such cases the upkeep of fans and motors is often an expensive item, and while the reliability of the modern fan-motor is vastly superior to its predecessors, it is by no means infallible.

It has been discovered that fresh air possesses a vitalising quality that is absent from conditioned air, or that which has traversed long lengths of ducting.

The unsatisfactory results of artificial ventilation are shown by the school ventilation investigations of the New York State Commission in the winter of 1926-1927.

Duffield* selected three newly-built schools where the latest type of plenum ventilation was employed, and three schools built approximately forty years before, naturally ventilated and furnace heated.

In a series of careful observations it was found that the children attending the old schools were affected by respiratory complaints to approximately half the extent of those attending the modern schools.

The conclusion was reached that the large air movement produced by plenum systems especially with high room temperatures, was connected with the excessive number of respiratory affections experienced by the occupants of buildings so ventilated.

Many observations and experiments have been carried out in an attempt to define the quality possessed by fresh air which is absent in mechanically-conditioned air without any satisfactory physical explanation being arrived at.

This phenomenon is probably due to the difference in the quality of air movement obtaining with such a system and that prevailing in the open air. The former conditions being monotonous, the air in a room is not made to move bodily as it does outside, but is split up into small but constant currents of various velocities and sizes according to the position and sizes of the inlets and outlets, whereas air movement out-of-doors is continually varying and takes place on a much larger scale.

Such artificial conditions are not conducive to bodily health and that sensation of alertness and *joie de vivre* experienced by the man whose occupation enables him to remain in the open air.

---

* T. J. Duffield, *Am. School Board Journal.* January, 1928.

From the observations of Duffield previously mentioned, it would seem desirable to introduce fresh air to a building directly from the outside, and if it is necessary for this air to be heated, the above principle may be extended to involve a system of multiple heater units situated near the outside walls each with its own short air intake. This scheme will be described later.

I do not wish these statements to be interpreted as a wholesale condemnation of central air-conditioning systems, or of fan ventilation in general. There are, indeed, many types of ventilation problems that can only be solved by such mechanical systems, notably when high air velocities are necessary to cool some apparatus or manufacturing process, or when a number of rooms with no outside walls are to be ventilated, and for mines, tunnels, etc.

In such cases mechanical ventilation is the only solution, but as pointed out by Frederick, the absurdity lies in proclaiming a virtue out of a necessity, and in the unnecessary fitting of such systems as an alleged improvement on natural ventilation.

Return to Simpler Methods.

The history of man's endeavour to emulate the achievements of nature shows that the sequence of development is always the same. He starts with clumsy and complicated apparatus, and obtains results far inferior to those which nature produces with apparent simplicity, and as knowledge on a particular subject is enhanced, it is discovered that nature's way of doing a job is usually the most efficient, and to obtain her results her methods must be employed, whenever possible.

Consider, for instance, the development in aviation, what clumsy contraptions were the first aeroplanes, slow and dangerous, bristling with external struts and projections, bearing no resemblance to the natural flying machine, the bird.

To-day the modern aircraft, seen from a distance, may easily be mistaken for a bird. Its shape is almost identical in its beautiful simplicity, and the result is increased efficiency.

Just as the aeronautical engineer is learning to keep his machine aloft for hours without an engine, so is the ventilating engineer learning to move large volumes of air from a building, without resorting to mechanical devices.

Knowledge gained by research into the subject indicates that in the ventilation of buildings we may successfully use the method employed by nature in the ventilation of the earth's surface.

Cosmic Ventilation.

The energy for producing movement in the open air is supplied by gravity and heat from the sun.

For a given locality the latter is variable both in quantity and manner of absorption, and this variation creates movement in the atmosphere and cosmic ventilation, in the following manner :—

Air is heated indirectly by the sun over a limited area, this reduces its mass-volume ratio due to expansion, and cool air due to its greater weight is drawn underneath it by gravity. The result is almost continuous vertical and horizontal air-currents, the latter being more evident at ground-level.

Now let us follow the air movement taking place in a naturally enclosed space, such as a narrow valley, which may be regarded as corresponding to a building, in that it is formed of more or less vertical walls which prevent the wind from blowing through it in certain directions.

When the air in such a space becomes warmer than the surrounding atmosphere, cold air flows in at the bottom of the two sides and forces it upwards, thus producing an air change even on a windless day, and should a wind be blowing across the crests of its hills the air flow will be increased.

The Ventilator.

This is the principle used in natural ventilation, and is the same action that took place over the primitive hole in the roof. Wind blowing across the open end of a pipe will induce an air flow through it in the same manner, such a pipe fitted vertically through the roof of a building would make a good extractor, both by virtue of the induction effect of passing winds, and the air flow produced by the difference in temperature between the air inside it and that outside.

This is known as stack action or thermal action.

For instance, an excess temperature of 10° F. inside a stack of 50 ft. in height would create an air flow of 242 ft. per min.

But an open pipe would let the weather in, and the fitting of devices to prevent this and to increase the suction power has produced the modern roof ventilator. The many types of ventilators now on the market vary to an astonishing degree in their efficacy, some are almost useless and show the maker's ingenuity in construction, and regard for appearance, to greater advantage than his knowledge of aerodynamics.

Now a ventilator must offer the least possible resistance to the upward air flow due to temperature difference, it must obtain the maximum induction effect from outside winds, it must not allow a backward flow of air under any wind direction, and it must be weatherproof.

Finally, to formulate intelligent ventilation schemes the manufacturer must know the exhausting capacity of his ventilators under the various conditions likely to be encountered.

A fair question to put is what happens when there is no wind and no temperature difference.

Actually such a condition is practically unknown. Even if the air in a room at head-level is the same as that outside, the air near the roof will be warmer, due to the presence of the occupants, and usually, if there are no occupants ventilation is of little importance.

Also, the atmosphere is never at rest, and it is interesting to note that one type of ventilator with a 54-in. diameter throat will exhaust one thousand cubic feet of air per minute from the induction effect of wind alone at 2 miles per hour, and no temperature difference.

This wind velocity is too low to be felt on the face, and such a condition would commonly be called " still air."

Approximately ten years ago the United States Bureau of Standards conducted tests of about fifty ventilators, of standard makes and the same size.

These tests determined the air speed produced in the standard size of ventilator pipe by the induction effect of outside wind, by placing each ventilator in an air stream produced by an adjacent wind-tunnel and power-fan, the induced air flow being measured by an anemometer placed in the ventilator stack-pipe.

While the efficiency of a ventilator depends primarily on its suction capacity, stack action is also an important factor, and the baffling effect of the suction and weathering devices were measured by blowing air first through an open pipe and then through the same pipe with a ventilator fitted over its end, the reduction in velocity represented the resistance to stack action of the particular design under test.

These tests indicated that—

There is a great difference in efficiency between the various types of ventilators.

Most of the fifty models tested were inefficient.

Highest efficiency may be obtained with ventilators of simple design.

The most effective way of obtaining a large volume of air exhaust is to prevent the air from entering the ventilator, for any air that enters must be exhausted with and at the expense of the upward flow of air in the ventilator pipe.

The most satisfactory ventilator had a resistance to stack action of 12 per cent., and effected an induced air flow through the stack-pipe of approximately 29 per cent. the velocity of the actuating wind, this latter result being obtained with no temperature difference and therefore without the aid of stack action.

An efficient modern ventilator will offer as little as 3 per cent. resistance to stack action and induce an air flow of approximately 35 per cent., the velocity of the outside wind.

The resistance figures were, of course, taken at the same air speeds but the static-pressure curve is practically flat at the velocities obtained with a natural ventilator.

It is claimed that some ventilators will induce an air flow equal in velocity to the outside wind, but this is virtually effected by placing a large ventilator on a small pipe, the increase in air speed being due to the choking or venturi effect produced in the stack-pipe which tapers from the ventilator and terminates in a comparatively small opening at its base, the anemometer readings being taken at this point where the velocity is greatest. This scheme does not increase the volume of air exhausted ; on the contrary it means using a large ventilator in an inefficient manner, as a small pipe is fitted to choke the outflowing air and increase its speed to create an illusion of efficiency.

Effect of a Sloping Roof.

It is obvious that in laboratory research, ventilators must be tested under similar conditions to those to which they would be subjected when mounted on the roof of a building.

As you are aware, the majority of roofs are built at an angle to the horizontal, usually about 30°, and when the wind is blowing across the ridge it is deflected in an upward direction as shown in the diagram (Fig. 1) ; moreover, it does not immediately curve over the ridge and follow the reverse slope of the roof, but continues for a distance in an upward direction as part of a gradual curve towards the ground due to the drop in air pressure on the lee-side of the building. This wind trajectory induces an upward flow of air over the lee-slope of the roof, so that an upward movement is produced on both sides.

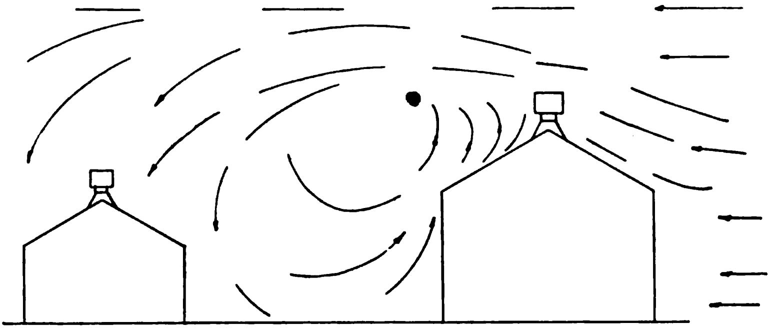


FIG 1.

This is easily demonstrated in the laboratory with the use of smoke-paper, and I was, in fact, treated to a natural demonstration of this on a large scale last summer during a big gorse fire on a hill in Wales. The wind was blowing across the crest, and the smoke clearly illustrated the air-currents, which bore out the results obtained in the laboratory.

Now the greatest and commonest mistake made by ventilator manufacturers is in designing their ventilators to function only in a horizontal wind.

The upward deflection of the wind caused by a sloping roof seriously impairs the efficiency of most ventilators. Many types cease to produce any air movement at all under such conditions, and some create a definite back-draught.

Now let us refer again to the diagram of the wind trajectory. We see that the wind curves into a downward direction beyond the lee-side of the building, the distance away depending on the wind speed. If a building is situated at this point and equipped with ventilators, they will be subjected to this downward air-current, and under such conditions most ventilators will back-draught.

It is, therefore, obvious that an efficient ventilator must not only resist the entry of upward or downward air-currents, but must utilise them to induce an air flow. That is, a ventilator must employ the kinetic energy of the wind irrespective of its direction.

Louvred Lanterns.

Louvred lanterns are used to effect ventilation in many industrial buildings. These only achieve their object when the wind is blowing in line with the roof ridge. When it is blowing on to the louvres such a structure produces a back-draught, more air being admitted on the windward side than is exhausted on the leeward side. Moreover, the air does not pass directly from one side to the other, but sinks into the building causing unpleasant down-draughts on the occupants.

Wind-Motor Ventilators.

Before we leave the subject of ventilator design I will describe one other type. This is a combination of a mechanical and natural ventilator.

It employs a wind-motor to operate an extraction fan.

The sketch (Fig. 2) is an example of this type.

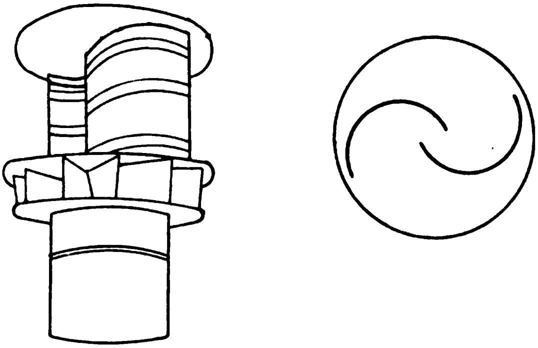


FIG. 2.

It will be seen that the wind-motor is composed of two half-cylinders slightly overlapping in the centre. This always rotates in the same direction, irrespective of the point of the compass from which the wind is blowing. The gap made by the overlap in the centre allows air to pass through to the back of the other blade and so reduce the partial vacuum that would otherwise be set up on the lee-side.

This particular type of wind-motor is very efficient and is used to produce power for various purposes. In a ventilator a semi-centrifugal fan is fixed direct to the bottom of the wind-motor.

Its chief advantage as a ventilator is that it will work against a greater resistance than the ordinary induction type.

Its disadvantages are : That like most ventilators it is only designed to function in a horizontal wind. It will not rotate in the very low wind speeds at which an induction ventilator would still be functioning efficiently.

Its design baffles and reduces the exhaust due to thermal action when the rotating portion is at rest.

Its volume of exhaust is less per unit area of stack-pipe at normal wind speeds than an efficient induction ventilator, unless the wind-motor and fan are made exceptionally large in proportion to the stack-pipe, which is not done.

Then, of course, there is the extra cost due to its complicated design, and the inconvenience of having moving parts situated in inaccessible positions on the roof of a building.

Resistance to Air Flow.

If a resistance of any magnitude is placed on the air supply a natural ventilator will not function, the average maximum may be taken as approximately 0.1 in. w.g.

Such resistances may be imposed by providing an insufficient area of openings for the admission of fresh air to a building, or in restricting an otherwise adequate area by fitting registers with an inadequate effective area of openings.

Another source of resistance lies in complicated duct-work from ceiling to ventilator, or from room to room. All horizontal ducting should be avoided.

When ducting is necessary it should be carried vertically from the ventilator base to the ceiling, and be of a larger sectional area than the ventilator stack-pipe. Ceiling registers should also have a larger effective area of openings than the ventilator stack-pipe.

If two rooms must be served by one ventilator then the branch ducts should be at as steep an angle as possible.

It must be borne in mind that the air flow produced by a natural system is of low velocity and low head, and therefore all ducts and openings must be of large area and low resistance.

It is usually a simple matter to arrange fresh-air intakes and ducts of suitable dimensions to obviate any appreciable resistance being put on the air stream during its route through the building. This, indeed, is proved by the fact that in practice it is possible to effect from 20 to 60 changes per hour in the average building, the actual amount depending on the height, and total length of roof ridging to accommodate the ventilators in proportion to the cubic contents of the building.

It therefore follows that there is little demand for a more powerful suction than that produced by the ordinary induction type of ventilators.

Fresh-Air Intakes.

The importance of an adequate area of fresh-air intakes has already been stressed.

The greater the intake area, the lower the velocity of the incoming air and the less likelihood of draughts being felt.

The increment to the ventilator's exhausting capacity due to thermal action will vary directly with the vertical distance between the ventilators and the mean level of the air intakes, but it is not desirable to position these at floor-level owing to the inevitable draughts, especially in a high wind. The most satisfactory scheme is to position hopper type intakes at 5 or 6 ft. above floor-level. These deflect the incoming air into an upward direction, this air will then sink, due to its lower temperature and greater weight, and in a diffused state which renders it undetectable apart from the general cooling effect.

Radiators may then be used at floor-level to radiate heat to the feet and legs of the occupants. It is essential to health and comfort that the lower extremities be kept warm, and this object is defeated if intakes allow cold air to blow in at floor-level.

With this system the feet and legs are warmed, while the air at head-level is comparatively cool, which is an ideal arrangement, producing healthier conditions than would obtain with hot-air heating.

If the incoming air is heated, then the level of the intake openings should be lower, as such air would not sink after entering the building. The velocity of the incoming air should not exceed 3 lin. ft. per sec. in calm weather, but when a wind is blowing into the openings this will, of course, be increased. For this reason the outside openings should be shielded as much as possible from the wind, and it is an additional reason for deflecting the incoming air into an upward direction. Intake passages should be as short as possible to minimise friction and the collection of dust.

Any high openings into a building should be closed, as there is a tendency for the incoming air to heat up and rise before sinking to head-level, which is wasted air movement, and such air, sinking in a diffused state from a greater height, will press some of the vitiated air back to breathing-level, and, of course, such openings will raise the mean level of the intakes and so reduce the thermal action.

If the room to be ventilated is below ground-level, fresh air may be introduced by dropping ducts from ground-level to a point approximately 2 ft. above the floor, constructed preferably of some insulating material. The cooler air from outside will flow down such ducts, owing to its density being greater than that of the air in the room, and to the suction of the ventilator.

Natural ventilators are frequently installed on a building where fans are already in operation. If they are extractor fans, they should be reversed, if possible, to form additional air-intakes, care being taken to deflect the air downwards and in a direction where it will cause the least possible inconvenience from draught.

If they cannot be reversed, or if they are being used to extract fumes from some localised plant, great care should be taken to ensure that an adequate area of intake openings are arranged to admit sufficient air for the ventilators and fans, otherwise the fans will starve the ventilators of their air supply or even cause them to act as intakes. The same precautions must be taken in any building containing air-consuming plant, such as boiler-houses.

Ventilators and Unit Heaters.

Natural ventilation has been successfully used in combination with indirect-heating—heating being effected by unit heaters, the intake side of each unit is connected to a short duct through a wall or roof and fitted with a damper, which may be shut together with the ventilator dampers during the warming-up period. This system is increasingly popular for industrial buildings, and has the advantage that it can be easily and economically extended.

Fans in Ventilators.

A large air movement is sometimes required for short periods ; such is desirable, for instance, in a foundry during the pouring process, especially if the building is of comparatively small size, whereas normal ventilation only would be required at other times.

To meet such a demand roof ventilators are frequently installed with fans of suitable design and relative size fitted inside them. The fans are only switched-on when a large air movement is required. At other times the ventilator is functioning in the normal manner.

When the fan is in operation the total volume of air exhausted from the ventilator will be greater than the normal capacity of the fan, provided that the static head is not greater than the velocity head due to the natural forces. When these two equalise, the volume of air exhausted will be equal to the capacity of the fan. The point at which they equalise will depend on the velocity of the air flow and the resistance offered by the ventilator.

For example, one type of ventilator fitted with a fan which is capable of producing an air flow of 900 lineal ft. per min. will increase the total exhaust by 25 per cent. of the ventilator's natural capacity.

Filters.

The average resistance to air flow of an efficient filter is in the region of 0.1 in. w.g. for low air speeds. It therefore follows that a natural ventilation system with a maximum working head of 0.1 in. w.g. would be incapable of drawing air through it.

If it is necessary to filter the incoming air then a fan must be used to overcome the resistance, otherwise such screens would virtually cut off the air supply.

Positioning of Ventilators.

The locating of ventilators on a building and their position with regard to other adjacent structures is of even greater importance that the arrangement of air-intakes.

Wind is the major energising factor of a ventilator, and any structure will change the force and direction of the wind in its immediate vicinity, the zone affected varying with the velocity.

Ventilators fitted near to other structures may be subjected to upward, downward, horizontal or eddying air-currents, or be situated in a high-pressure zone, caused by the wind blowing directly on to a vertical wall ; such high pressure would persist for a definite distance back from the wall, the depth remaining fairly constant with varying wind speeds. If, however, the wind is blowing into a cul-de-sac the high-pressure zone will be much deeper. Ventilators subjected to these latter conditions will obviously back-draught irrespective of their design, owing to the air pressure outside the ventilator being higher than that in the building.

Eddying air-currents will considerably reduce the exhaust of the best-designed ventilators and will cause back-draughting in the less efficient types, which are in the majority. Eddying air-currents and high-pressure zones must therefore be avoided.

Most ventilators attain their maximum efficiency in a horizontal wind, and should be fitted where such a wind can blow over them, whenever possible. If they must be subjected to an upward or downward wind then they must be designed to function under these conditions.

It is often necessary to mount ventilators on stack-pipes to raise them clear of unfavourable air-currents caused by adjacent structures, and when long external stacks are used it is an advantage to lag them with non-conducting material to maintain the temperature of the air inside and reduce condensation. This is, of course, especially desirable when the ventilators are being used to extract steam or air of high humidity, and gutters should be fitted at the base to prevent condensate from dripping into the building.

Control.

Owing to the influence of temperature difference on the exhausting capacity of a roof ventilator, a certain degree of thermal balance is obtained with this system, but the low outside temperature and high winds in winter time would effect too much ventilation and consequently heat extraction, with a system designed to ventilate efficiently during the summer months.

Controlling dampers should therefore be used to reduce the exhaust when necessary.

Where a number of ventilators are mounted in line, the dampers may be coupled up and operated from one point.

The control of a natural system should not be confined to the intakes, as serious draughts may be created by the ventilators drawing air at a comparatively high speed through incidental openings, such as broken windows, spaces under doors, etc.

Quality of Air Movement.

A properly-designed natural system, unlike mechanical ventilation, does not produce a multitude of separate air-currents.

Provided that wind is not allowed to blow directly into the building, the upward movement of air will be uniform, its velocity depending on the exhaust of the ventilators.

Incoming air does not rise directly to the ventilators, but spreads laterally through the building at a level determined by its temperature. The air movement is not constant and monotonous like fan ventilation, but varies with the outside wind and the temperature difference, thus possessing that important characteristic of open-air conditions—variability.

The frequency of air changes in a building is not necessarily proportional to the volume delivered by fans, as a large percentage of such air will leave the building in a comparatively fresh condition, while pockets of stale air remain, and the churning produced by the majority of mechanical systems will return expired air to breathing level.

The wholesale movement produced by a natural system ensures a frequency of complete air changes proportional to the volume extracted. Bacteria-laden air expired from the lungs will rise owing to its temperature and humidity, and with such a system will not return to breathing level ; it has been established that an upward air movement greatly reduces catarrhal infection.

The mechanical ventilation system installed in the Houses of Parliament delivered a volume of air per hour equal to ten times the cubical contents of the building, and although the chemical condition of the air was good the ventilation was notoriously bad.

Such cases as this indicate that the quality of the air movement is of equal importance to the quantity.

It is of even greater import to comfort in living quarters than chemical purity.

Moisture Removal.

The chief causes of discomfort in badly ventilated rooms are high temperatures and humidity and both these factors are associated with the incidence of catarrhal infection. Fortunately, they are also motive forces in natural air movement.

The density of water vapour and air is in the ratio of 0.623 to 1, so that humid air will rise above dry air at the same temperature.

Therefore the excess humidity of the air in a room will increase its buoyancy and consequently the exhaust of the ventilators.

For the same reason a natural system is particularly efficacious for dealing with steam removal problems.

There are many successful steam removal plants in operation, relying entirely on natural ventilators and hoods. There is, for example, a jam factory in the London district using a " natural " installation for this purpose. A number of pans containing boiling jam are covered by a hood terminating in a ventilator with a throat diameter of 54 in. which deals adequately with all the steam produced, amounting occasionally to 5 tons per hour.

This is not so remarkable as might be supposed when it is realised that a ventilator of this size will exhaust 6,390 cu. ft. of air per minute, which represents 13 tons of dry air per hour at 60° F.

The necessary conditions for this performance with the type of ventilator used in this case would be a difference in temperature of the air inside and outside the building of 20° F., a height of 20 ft. between the air-intakes and the ventilator, and that it may be subjected to a wind velocity of 6 m.p.h.

Condensation.

Condensation of water vapour in air occurs when the temperature drops below the dew-point, but the dew-point varies with the relative humidity, so that this phenomenon may occur with an increase of moisture or drop in temperature, or both.

There are two precautions to be taken in avoiding or reducing condensation, firstly to construct the building from material having a low coefficient of heat transmission to ensure that the temperature of the inside surfaces may be as near as possible to the temperature of the inside air. This would allow the air to be nearer to its dew-point without condensation occurring on the cooler surfaces, and material having high radiating properties should be avoided or covered as much as possible, for when the heating system is closed down, the radiation from such material exceeds the absorption and its temperature may drop below the dew-point of the ambient air.

But the most efficacious, and frequently the only method of preventing condensation is to replace the humid air with drier air, and as the former naturally rises to the highest point of a building, natural ventilators are particularly suitable for this purpose, the effect of such a system being to increase the margin between the inside temperature and the dew-point.

Fume Removal.

Natural ventilation is obviously suitable for removing " lighter than air " fumes but it is not so widely known that this system can be successfully applied to the removal of " heavy " fumes. The old downward system of mechanical ventilation was based on the erroneous belief that CO_2 lay in a concentrated form at floor-level.

Except in heavy concentrations and in still air, such fumes will become more or less evenly diffused in the atmosphere and may be extracted by a natural system of suitable proportions.

The exhausted gases from an internal combustion engine are frequently regarded as heavy low-lying fumes, due probably to their being ejected at a low level and to the knowledge that CO_2 is present, but it also contains carbon monoxide and water vapour, both of which are lighter than air, and the whole mixture, being warm when leaving the engine, rises, and may easily be extracted by a " natural " system of suitable design.

Tropical Ventilation.

Those who have experience of tropical conditions will no doubt aver that the temperature is frequently lower inside a building than outside and that air may be expected to flow downwards through a roof ventilator in the absence of wind, but due to the diathermanous property of air there is actually very little difference in the temperature at head-level in a building with open doors or windows to that of the outside air, the excess registered temperature outside being due mainly to radiation.

But the roofs of such buildings will absorb a considerable amount of heat from the sun and transmit this by conduction to the air immediately below, thus raising the mean temperature of the inside above that of the outside air and producing a flow through the ventilators in addition to that induced by wind. The above applies chiefly to industrial buildings, stores, etc.

Living quarters are usually opened at night time to admit the cooler air and closed in the day time, low-speed fans being used to agitate the air but not to change it. Such buildings are equipped with double roofs and natural ventilators may be used with advantage to effect an air flow between the two roofs and reduce the heat transmitted to the inside of the building.

Criterion of a Natural Ventilator.

A ventilator must be weatherproof and of reasonably good appearance. It must not back-draught when fitted in the position recommended by the makers ; it must be constructed of suitable material to resist any corrosive agents to which it may be subjected, and its weight should not be excessive, as the strengthening of roofs to support large sizes increases the cost of an installation.

The exhausting capacity under given conditions should be guaranteed, and provided that a number of ventilators are satisfactory regarding the above points, they may be judged on a basis of cost per cu. ft. of exhausting capacity per unit time under the same conditions, which should be representative of those likely to be encountered with a well-designed system.

Finally, the fitting of efficient ventilators does not necessarily mean efficient ventilation.

The system must be applied scientifically, factors of apparent insignificance to the inexperienced may render a natural ventilator useless.

Conclusion.

I have endeavoured to portray natural ventilation in true perspective.

A system to be regarded, not as a make-shift and an unknown quantity, but an exact science, and capable of producing atmospheric conditions which approximate more closely to those existing in the open air, and under which the human machine was evolved to function. Ventilation is a fascinating subject of significance to everybody, and the extent of its influence on physical and mental energy and well-being is not sufficiently appreciated.

PIPE SIZING FOR HOT AND COLD WATER SUPPLY SERVICES

By W. E. FRETWELL (Vice-President)

PAPER READ BEFORE THE INSTITUTE OF PLUMBERS
BATH, MARCH 14th, 1934

Discharge of Water Through Pipes.

Every subject is obscure until its fundamental principles are clearly understood. The object of this paper is to endeavour to explain in simple language some of the more important physical laws controlling the flow of water through pipes and the effect of such laws on the outflow therefrom.

Unlike man-made laws, physical laws are immutable.

Pressure Head.

Where water flows through pipes the energy producing motion is expressed in terms of pressure-head of water or its equivalent. The pressure head is the vertical distance between the free level of water in the supply cistern and the centre of the orifice from which it flows.

Velocity of Efflux.

The velocity of efflux, i.e., that velocity at which a fluid particle leaves the orifice of the system, can never exceed that acquired by a body falling *in vacuo* through a height equal to the pressure-head. *Equation No.* 1.

$$v^2 = 2gh$$

This well-known equation gives the velocity where

v = velocity in feet per second.
g = acceleration due to gravity.
h = the height in feet through which the body falls.

In order to simplify calculations the value of g is taken in this paper as 32 instead of the more correct figure of 32.2 feet per second per second.

By taking the square root of each side of Equation No. 1 we obtain :—

$$\begin{aligned} v &= \sqrt{2gh} \\ &= \sqrt{2 \times 32 \times h} \\ &= \sqrt{64h} \\ &= 8\sqrt{h} \end{aligned}$$

Equation No. 2.

$$v = 8\sqrt{h}$$

Equation No. 2 gives the theoretical velocity in feet per second acquired by a falling body as eight times the square root of the height in feet through which it falls.

By transposition we obtain

$$\sqrt{h} = \frac{v}{8}$$

Squaring both sides of this equation gives

$$h = \left(\frac{v}{8}\right)^2$$

from which is obtained

Equation No. 3.

$$H_V = \frac{v^2}{64}$$

where H_V = head in feet required to produce a velocity of v feet per second.

Example. Suppose the velocity of efflux to be 8 ft. per second, according to Equation No. 3

$$H_V = \frac{v^2}{64}$$

The head H_V in feet required to produce a velocity of 8 ft. per second is therefore

$$\frac{8^2}{64} = \frac{64}{64} = 1 \text{ foot.}$$

Pressure Drop through System, Fig. 1.

The system shown by Fig. 1 will serve to explain the conditions obtaining when water flows through the discharge pipe.

The water level A in the system is presumed to remain constant.

The vertical distance or head between the water level and the centre of the outlet orifice is 10 ft.

The gauge tubes lettered B, C, and D are supposed inserted into the side of the pipe. These gauges register what is called the static head or bursting pressure on the system.

Imagine water to outflow with a uniform velocity over the orifice of 8 ft. per second.

The theoretical height through which a body must fall from rest to acquire a velocity of 8 ft. per second is, as already determined, 1 foot.

The velocity head H_V, shown on the outlet end of the pipe is, therefore, 1 foot.

The friction head encountered by water flowing over the surface of the pipe itself is herein denoted by the symbol h_{f1}, h_{f2}, etc., where the suffix $_1$, $_2$, etc., represents the appropriate section of piping.

The total or sum of the friction heads is represented by the symbol H_f.

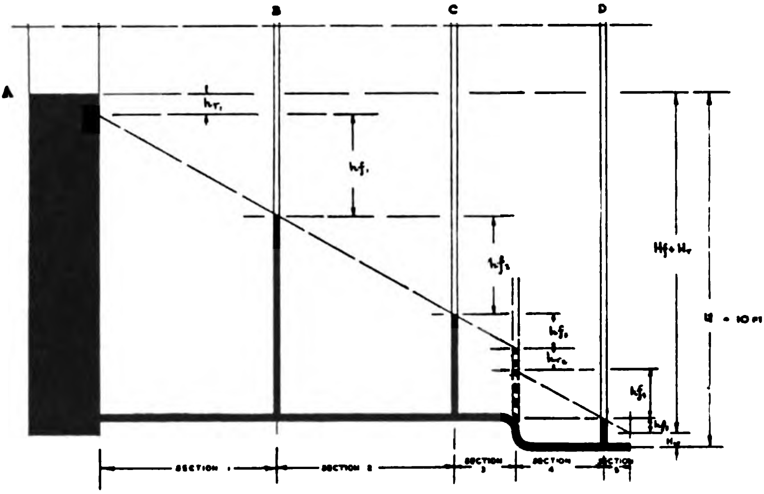


FIG 1.

The symbol, h_{r1}, h_{r2}, etc., represents the resistance to flow of water occasioned by a sudden change in the direction of flow.

The suffix $_1$, $_2$, etc., represents the appropriate changes of direction.

The sum of these resistances is represented by the symbol H_r.

Equation No. 4.

$$H = H_v + H_f + H_r.$$

Equation No. 4 represents in effect a balance sheet in which H represents the capital invested and $H_v + H_f + H_r$ the expenditure.

The importance of understanding this fundamental law cannot be too strongly stressed.

The following explanation shows how the pressure head is consumed when water outflows from the system (Fig. 1).

1. The resistance to the flow of water entering the pipe at the cistern results in a pressure drop indicated by the head h_{r1}.

   This drop in pressure is indicated by the difference in height between the surface water level A and the top of the sloping line where it joins the cistern.
2. The friction of the pipe " section 1 " between the cistern and the gauge lettered B produces a pressure drop h_{f1}.

3. The friction of the pipe " section 2 " between the gauges B and C produces a pressure drop h_{f_2}
4. The friction of the pipe " section 3 " is indicated by h_{f_3}.
5. The resistances of the two bends between the pipe sections numbered 3 and 4 is indicated by h_{r_2}.
6. The friction of the pipe " section 4 " is indicated by the drop in pressure h_{f_4} on the gauge D.
7. The friction of the pipe between the gauge D and the end of the pipe is indicated by the pressure drop h_{f_5}.
8. The head required to produce the velocity of efflux is indicated by H_v.

The total pressure drop of the system shown in Fig. 1 is as follows :

(*a*) Head consumed by friction of pipes $= H_f = h_{f_1} + h_{f_2}$ $h_{f_3} + h_{f_4} + h_{f_5}$.

(*b*) Head consumed by resistances $= H_r = h_{r_1} + h_{r_2}$.

(*c*) Head due to velocity of efflux $= H_v$.

Whence $H = H_v + H_f + H_r$.

In the system (Fig. 1) a head (H_v) of 1 ft. is required to produce a velocity of efflux of 8 ft. per second.

The total head (H) is 10 ft. Deducting the required velocity head of 1 ft. gives 9 ft., and this represents the sum of the frictional losses of the pipes and the resistances due to sudden changes of direction, etc.

Summary.

Whenever water flows through a pipe system it always conforms to the equation $H = H_v + H_f + H_r$.

Pipe Discharge Formula.

From what has already been said it is clear that the flow of water through pipes is controlled by physical laws and not by formulæ.

Pipe discharge formulæ are at best an attempt to evaluate the frictional resistance to flow of water of varying temperatures and velocities of flow through pipes of different sizes and having, in most cases an unknown frictional surface effect on the flow.

It is obvious that unless, in a pipe discharge formula the value of certain factors are changed, or new ones introduced, the calculated discharge cannot be true for smooth lead or copper pipes and for commercial mild-steel screwed tubing.

Apart from the relative smoothness of the pipe surface, the bore of lead and copper pipes more nearly conforms to the nominal diameter than does mild-steel screwed tubing, in which the external diameter is, for a given size of tube, more or less constant for tubes of gas, water and steam qualities. In addition more fittings are usually employed on screwed mild-steel tubing than for lead and copper pipes.

No two formulæ for pipes discharge give the same result, and it is doubtful whether, in practice, the calculated discharge ever exactly agrees with that actually obtained.

The object of employing a pipe discharge formula should be to ensure that the pipe system is large enough to provide the desired outflow of water without employing unnecessarily large diameter pipes.

"Box" Formula.

In this paper the well-known formula of Thos. Box for the discharge by long pipes is employed because of its simplicity of application and not because it is claimed that the results are more accurate than those obtained by other formula of a later date.

The formula of Thos. Box is expressed as :—

Equation 5.

$$G = \sqrt{\frac{(3d)^5 \times H}{L}}$$

Where G = gallons per minute.
d = diameter in inches.
H = head in feet.
L = length of pipe in yards.

Other derived equations are :—

Equation 6.

$$H = \frac{G^2 \times L}{(3d)^5}$$

Equation 7.

$$L = \frac{(3d)^5 \times H}{G^2}$$

Equation 8.

$$d = \left(\frac{G^2 \times L}{H}\right)^{\frac{1}{5}} \div 3$$

Table No. 1.

This table was calculated by the author several years ago, and is based on equation No. 5, and may be usefully employed for pipe discharge calculations.

It should be noted that Box's formula, from which the table is calculated, gives the discharge from long pipes. If used for short pipes and heads of less than 1 ft. or thereabouts, the table gives results in excess of those obtained in practice.

TABLE I.

TABLE FOR DETERMINING DISCHARGE OF WATER IN GALLONS PER MINUTE ACCORDING TO FORMULA OF THOS. BOX. (COMPILED BY W. E. FRETWELL.)

Values of Length over Head.	Diameter of Pipe in Inches. ½	¾	1	1¼	1½	2	2½	3	4
1.0	4.77	13.1	27.0	47.0	74.0	152.7	268.0	420.0	860.0
1.2	4.35	12.0	24.6	43.2	68.0	139.4	243.0	384.0	790.0
1.4	4.03	11.1	22.8	40.0	63.0	129.0	225.0	355.0	730.0
1.6	3.77	10.4	21.38	37.4	58.8	120.7	211.0	332.0	680.0
1.8	3.55	9.8	20.16	35.2	55.5	113.9	198.0	313.0	643.0
2.0	3.37	9.3	19.1	33.4	52.6	108.0	188.6	296.0	610.0
2.5	3.02	8.3	17.1	29.8	47.0	96.6	168.6	256.0	546.0
3.0	2.75	7.6	15.6	27.2	43.0	88.1	154.0	243.0	499.0
4.0	2.38	6.6	13.5	23.6	37.0	76.3	134.0	210.0	432.0
5.0	2.14	5.9	12.0	21.2	33.0	68.3	118.0	188.0	385.0
6.0	1.95	5.4	11.0	19.3	31.0	62.3	108.0	173.0	350.0
7.0	1.8	5.0	10.2	17.8	28.0	57.7	101.0	159.0	326.0
8.0	1.69	4.6	9.5	16.7	26.4	54.0	94.0	148.0	304.0
9.0	1.59	4.4	9.0	15.7	25.0	51.0	89.0	140.0	288.0
10.0	1.5	4.16	8.5	15.0	23.5	48.0	84.0	133.0	270.0
11.0	1.43	4.0	8.15	14.2	22.4	46.0	81.0	126.0	260.0
12.0	1.38	3.96	8.0	13.62	21.5	44.1	77.0	122.0	249.0
13.0	1.34	3.65	7.5	13.1	20.6	42.0	74.0	116.0	240.0
14.0	1.27	3.5	7.2	12.6	20.0	40.6	71.0	113.0	230.0
15.0	1.23	3.4	7.0	12.2	19.2	39.4	69.0	109.0	223.0
16.0	1.2	3.3	6.7	11.8	18.6	38.0	66.0	105.0	216.0
17.0	1.16	3.18	6.6	11.4	18.0	37.0	64.6	102.0	210.0
18.0	1.12	3.1	6.37	11.0	17.6	36.0	63.0	99.0	203.0
19.0	1.1	3.05	6.2	10.75	17.1	35.0	61.2	96.0	198.0
20.0	1.07	2.95	6.05	10.5	16.7	34.1	59.7	94.0	194.0
22.0	1.02	2.8	5.76	10.05	15.9	32.5	57.0	89.5	184.0
24.0	.975	2.7	5.5	9.65	15.5	31.0	54.0	86.5	175.0
26.0	.947	2.58	5.3	9.26	14.6	29.7	52.3	82.0	170.0
28.0	.9	2.5	5.1	8.9	14.0	28.8	50.5	79.5	163.0
30.0	.87	2.4	4.95	8.6	13.6	27.8	48.8	77.0	158.0
32.0	.84	2.32	4.76	8.3	13.2	27.0	47.4	74.3	154.0
34.0	.82	2.24	4.63	8.06	12.7	26.2	46.0	72.0	147.0
36.0	.79	2.18	4.5	7.84	12.3	25.5	44.6	70.0	143.0
38.0	.775	2.12	4.37	7.63	12.0	24.8	43.5	68.0	140.0
40.0	.75	2.08	4.25	7.5	11.75	24.0	42.0	66.5	135.0
45.0	.712	1.96	4.03	7.05	11.12	22.76	39.8	62.6	128.0
50.0	.675	1.86	3.82	6.68	10.5	21.6	37.7	59.5	121.0
55.0	.635	1.77	3.64	6.34	9.98	20.6	36.2	56.6	116.0
60.0	.612	1.7	3.5	6.1	9.6	19.7	34.5	54.5	111.0
70.0	.57	1.56	3.25	5.63	8.85	18.2	32.0	50.0	102.0
80.0	.53	1.47	3.025	5.25	8.35	17.0	29.8	47.0	97.0
90.0	.505	1.38	2.84	4.95	7.8	16.2	28.2	44.2	91.0
100.0	.477	1.31	2.7	4.7	7.4	15.2	26.8	42.0	86.0
125.0	.427	1.17	2.41	4.2	6.6	13.6	24.0	37.5	77.0
150.0	.348	1.07	2.2	3.83	6.05	12.5	21.8	34.2	70.0
200.0	.337	.93	1.91	3.34	5.26	10.75	18.86	29.6	61.0
250.0	.302	.83	1.71	2.98	4.7	9.64	16.86	25.6	55.0
300.0	.276	.76	1.56	2.72	4.3	8.82	15.4	24.3	50.0
350.0	.255	.7	1.44	2.5	3.95	8.16	14.3	22.4	46.0
400.0	.238	.66	1.35	2.36	3.7	7.6	13.4	21.0	43.2
450.0	.226	.62	1.27	2.22	3.5	7.2	12.6	19.8	40.5
500.0	.214	.59	1.2	2.12	3.3	6.8	11.8	18.8	38.5
550.0	.207	.558	1.15	2.0	3.16	6.5	11.4	17.8	36.6
600.0	.195	.54	1.1	1.93	3.1	6.2	10.8	17.3	35.0
700.0	.18	.5	1.02	1.78	2.8	5.76	10.1	15.9	32.6
800.0	.1687	.465	.95	1.67	2.64	5.4	9.4	14.8	30.4
900.0	.159	.44	.9	1.57	2.5	5.1	8.9	14.0	28.8
1000.0	.151	.416	.85	1.5	2.35	4.8	8.4	13.3	27.0

Column 1 of Table I gives the L/H value and is obtained by dividing the length of pipe by the head. The discharge is given in gallons per minute abbreviated g.p.m.

For a pipe 40 ft. long and a head of 5 ft., the L/H value is $40 \div 5 = 8$.

For a L/H value 8, Table I gives the discharge from a 1-in. diameter pipe as 9.5 gallons per minute.

Example 1.—Calculate the head required to discharge 36 g.p.m. from a 2-in. pipe 72 ft. long.

For a 2-in. pipe carrying 36 g.p.m. Table I gives a L/H value of 18.

Dividing the length of 72 ft. by the L/H value of 18 gives $72 \div 18 = 4$.

The required head is 4 ft.

Example 2.—Calculate the length of 1-in dia. pipe to discharge 11 g.p.m. with a head of 5 ft.

For a discharge of 11 g.p.m. from a 1-in. pipe the table gives an L/H value of 6.

Multiplying the L/H value of 6 by the head of 5 ft. gives 30.

The length of pipe is therefore 30 ft.

General Rules for Pipes.

Box's formula purports to give the discharge by long pipes in which the head required to produce velocity of efflux is comparatively small and is, in consequence, ignored.

Where Box's formula is employed, the following general laws for pipe discharge obtain :—

Varying the Diameter.

According to the " Box " formula, the relative discharging power of pipes varies as the square root of the 5th power of the diameters.

The following table gives the relative discharging power of pipes, in which a 1-in. diameter pipe is taken as unity.

Diameter.	
¼ in.	0.03
⅜ in.	0.09
½ in.	0.18
¾ in.	0.49
1 in.	1.00
1¼ in.	1.75
1½ in.	2.76
2 in.	5.66
2½ in.	9.88
3 in.	15.59
4 in.	32.00

Example.—A 1¼-in. diameter pipe is calculated to discharge 15 g.p.m. What would be the discharge if the diameter is increased to 1½ in.?

Answer $= 15 \times \frac{2.76}{1.75} =$ 24 gallons approximately.

Conversely, a 1½-in. diameter pipe is calculated to discharge 24 g.p.m., what would be the discharge if the diameter is reduced to 1¼ in.?

Answer $= 24 \times \frac{1.75}{2.76} =$ 15 gallons.

Varying the Pressure-Head.

Where the diameter and length of pipe remain constant, the discharge varies as the square root of the head.

Example.—Suppose that for a head of 4 ft. the discharge from a given pipe is 10 g.p.m. If for the same diameter and length of pipe, the head is increased to 16 ft., the discharge would be

$$G_1 = G \times \sqrt{\frac{h_1}{h}}$$

Where G_1 = discharge under new condition of head in g.p.m.
G = „ „ original „ „ „
h_1 = the new head in feet.
h = the original head in feet.

Applied to the example, this gives :—

$$\begin{aligned} G_1 &= 10 \times \sqrt{\frac{16}{4}} \\ &= 10 \times \sqrt{4} \\ &= 10 \times 2 \\ &= 20 \text{ g.p.m.} \end{aligned}$$

Where for a given diameter the L/H value is constant, the discharge is unaltered.

Example.—For a 1½-in. diameter pipe, 40 ft. long, head 10 ft., the L/H value is $40 \div 10 = 4$, for which Table I gives a discharge of 37 g.p.m.

For a pipe 100 ft. long, head 25 ft., the L/H value is $100 \div 25 = 4$, for which the table gives a discharge of 37 g.p.m., as in the previous example.

Varying the Length.

Where the diameter and head remain the same, and the length only is altered, the discharge varies as the square root of the length.

Example.—Suppose that for a given head the discharge from a given pipe, 16 ft. long, is 10 g.p.m. If the length of pipe is increased to 64 ft., the head and diameter remaining the same as before, the discharge would be

$$G_1 = G \times \sqrt{\frac{L}{L_1}}$$

Where G_1 = discharge under new condition in g.p.m.
G = „ „ original „ „
L_1 = the new length in feet.
L = the original length in feet.

Applied to the example, this gives :—

$$G_1 = 10 \times \sqrt{\frac{16}{64}}$$
$$= 10 \times \sqrt{\tfrac{1}{4}}$$
$$= 10 \times \tfrac{1}{2}$$
$$= 5 \text{ g.p.m.}$$

If these examples are checked with Table I, they will be found to agree.

Resistance of Pipe-Fittings.

Every fitting, valve or connection causing a change in the direction of flow tends to set up turbulence and to resist the flow of water. The more abrupt the change of direction, the greater the resistance. A bend having a radius of not less than five times the diameter, and without constriction of the bore, is generally assumed to offer no more resistance than a pipe of the same length.

The resistance of fittings, valves and other obstructions is in this paper indicated by the letter r.

The resistance to flow of water through pipe-fittings, valves, and other obstructions, is generally referred to in terms of the resistance of a square elbow, the resistance of which is taken as 1.

The actual resistance to flow through fittings is more or less indeterminate. The resistance ratios for commonly used pipe-fittings, etc., are shown in Fig. 2. These ratios are rather higher than those commonly employed so as to allow for corrosion.

The resistance of pipe-fittings is frequently expressed in terms of the equivalent length of pipe of the same diameter offering the same resistance to the flow of water.

For the purpose of this paper, the equivalent length of straight pipe in feet for a unit resistance, $r = 1$ may be taken as shown in Table II.

TABLE II—DIAMETER OF PIPE.

Diameter of pipe in ins.	½	¾	1	1¼	1½	2	2½	3	4
Equivalent length in ft. for one resistance ..	1.0	2.0	2.5	3.5	4.5	6.0	7.5	10.0	14.5

Example.—Calculate in terms of straight piping the resistance to the flow of water through two 2-in. elbows and one 2-in. globe valve.

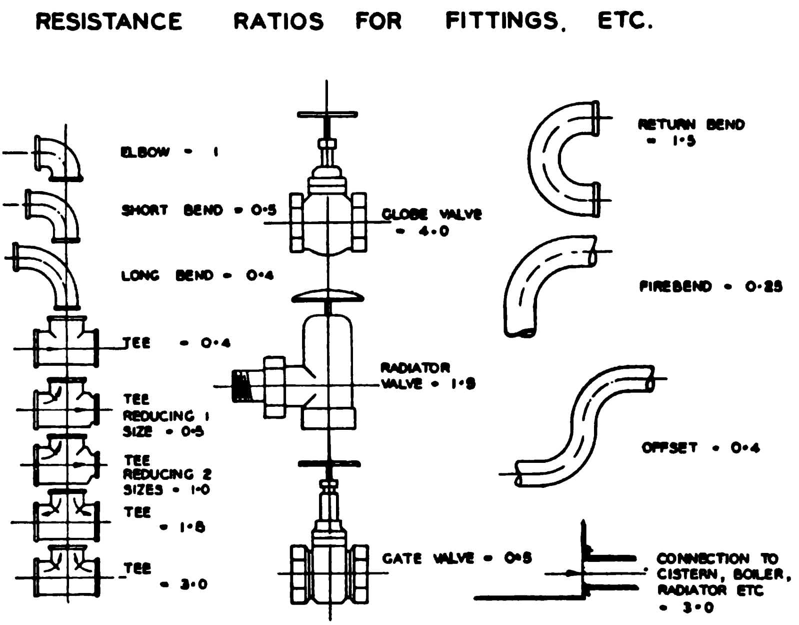


FIG. 2.

Referring to Fig. 2 the resistance ratio (r) for an elbow is 1 and that of a globe valve is 4.

The total of the resistance ratios is therefore

$$(2 \times 1) + (1 \times 4) = 6.$$

The equivalent length of pipe in feet for one resistance on a 2-in. pipe is 6.0, as shown in Table II.

The length of straight piping equivalent in resistance to two 2-in. elbows and one 2-in. globe valve is therefore 6 × 6.0 = 36 ft.

The discharge from a pipe is influenced by the arrangement of the pipe system.

In Fig. 3 the outflow end of pipe A rises above the dotted sloping line.

Assuming pipes A and B to be fully charged with water, the level of that in the gauge tube G cannot fall below the top of pipe A. The head of water above pipe A is 2 ft.

Pipe A is assumed to be 20 ft. long and pipe B 18 ft. long.

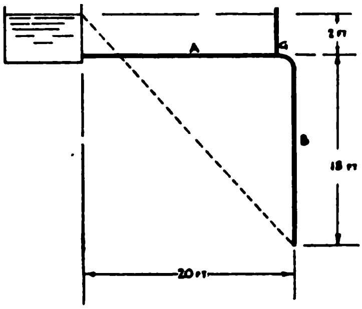


FIG. 3.

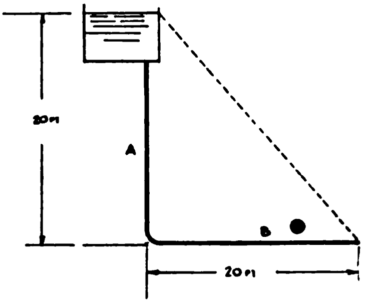


FIG. 4.

With the arrangement shown in Fig. 3, it is necessary first to calculate the required diameter for pipe A having a head of 2 ft. for the appropriate discharge.

Pipe A is 20 feet long, and the head available is 2 ft. The *L/H* value is, therefore, 20 ÷ 2 = 10.

For an *L/H* value of 10 and an assumed discharge of 20 g.p.m., a 1½-in. diameter pipe is required.

Pipe B is 18 feet long, and the head available is 18 ft., the *L/H* value being 18 ÷ 18 = 1.

For an *L/H* value of 1 and a flow of 20 g.p.m. a 1-in. diameter pipe is required.

In the arrangement shown in Fig. 3, a drop pipe 1-in. diameter will carry the whole of the water delivered by the 1½ in. horizontal pipe.

Fig. 4 shows an alternative pipe system in which the whole is below the dotted line.

Where this occurs the length of the pipes may be added together. In Fig. 4 the combined length of the pipes A and B is 38 ft.

For a pipe 38 ft. long and a head of 20 ft., the *L/H* value is 1.9.

For an *L/H* value of 1.9, Table 1 gives the discharge from a 1-in. diameter pipe as between 19.1 and 20.16 g.p.m.

With the alternative arrangement shown in Fig. 4, a 1-in. diameter pipe will just about meet the required discharge of 20 g.p.m.

Practical Applications.

Fig. 5 will serve to show the practical application of the principles explained.

Imagine that in the figure each of the six outlets is required to discharge 5 g.p.m. simultaneously.

The index, or least favourably placed outlet is that at the end of pipe No. 1. The dotted lines, B, C and D are imaginary gauge tubes.

When calculating a system of pipe diameters, some form of tabulation is desirable, such as those given in tabulations for Figs. 5, 6 and 7.

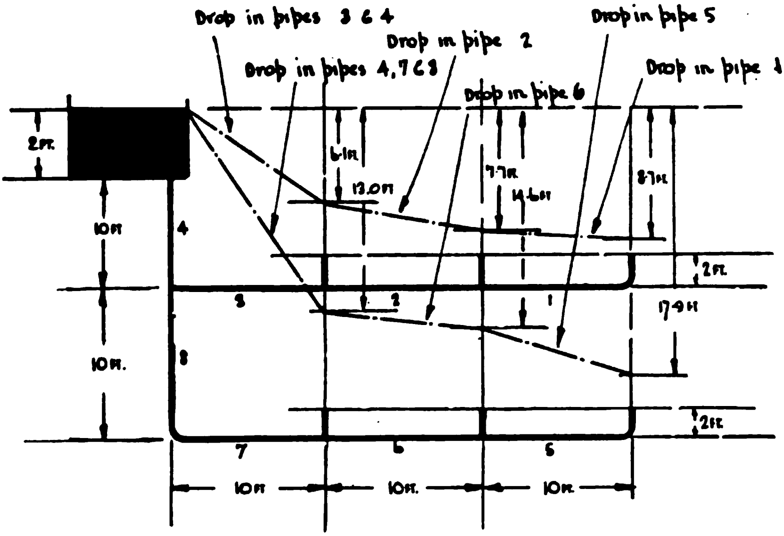


Fig. 5.

Column 1.

Column No. 1 gives the pipe numbers indicated on Fig. 5.

Column 2.

Column No. 2 gives the quantities of water in gallons per minute to be carried by the appropriate pipes in Column 1.

Column 3.

In such systems as that shown in Fig. 5 it is first necessary to assume the sizes of the pipes required. If these assumed sizes are too small the total head shown under Column No. 11 will exceed that available, shown in Column 12, and one or more of the pipes must be increased in size. Conversely, if the available head much exceeds that consumed by the pipes, one or more of the pipes may be reduced in size. Assumed diameters are shown in Column 3.

TABULATION FOR FIG. 5.

1 Pipe number	2 Gallons per minute.	3 Assumed Diameter, inches.	4 Sum of Resistances.	5 Length for $r = 1$.	6 Total length for resistances = products of columns 4 and 5.	7 Length of pipe.	8 Equivalent length = Sum of cols. 6 and 7.	9 L/H value	10 Head consumed = column 8 ÷ col. 9.	11 Total head consumed.	12 Head available.	13 Final Diameter, inches.
1	5	¾	5.5	2.0	11.0	12	23	7	3.3	3.3	10.0	1
2	10	1	0.4	2.5	1.0	10	11	7	1.6	4.9	10.0	1
3	15	1¼	1.0	3.5	3.5	10	14	10	1.4	6.3	10.0	1¼
4	30	1½	4.0	4.5	18.0	10	28	6	4.7	11.0	10.0	1½
					REVISIONS.							
1	5	1	5.5	2.5	14.0	12	26	28	1.0	12.0		
									Deduct	3.3		
										8.7	10.0	
5	5	¾	5.5	2.0	11.0	12	23	7	3.3	3.3	15.3	¾
6	10	1	0.4	2.5	1.0	10	11	7	1.6	4.9	15.3	1
7 and 8	15	1	2.0	2.5	5.0	20	25	3	8.3	13.2	15.3	1

TABULATION FOR FIG. 6.

1	2	3	4	5	6	7	8	9	10	11	12	13
Pipe number.	Gallons per minute.	Assumed Diameter, inches.	Sum of resistances.	Length for $r = 1$.	Total length for resistances = products of columns 4 and 5.	Length of pipe.	Equivalent length = Sum of cols. 6 and 7.	L/H value	Head consumed = column 8 ÷ col. 9.	Total head consumed.	Head available.	Final Diameter, inches.
1	5	1	4.5	2.5	11.0	10	21	28	0.8	0.8	15.0	1
2	10	1	0.4	2.5	1.0	10	11	7	1.6	2.4	15.0	1
3	15	1	0.4	2.5	1.0	10	11	3	3.7	6.1	15.0	1
4	20	1¼	1.0	3.5	3.5	10	14	5	2.8	8.9	15.0	1¼
5	20	1¼	4.0	3.5	14.0	10	24	5	4.8	13.7	15.0	1½
6	20	1½	5.0	4.5	22.5	26	49	14	3.5	17.2	15.0	1½
						REVISION.						
5	20	1½	4.0	4.5	18.0	10	28	14	2	19.2		
									Deduct	4.8		
										14.4	15.0	

NOTE.—In practice when taps are opened a flow of water would ensue through the secondary return, if any, and would assist to supply the taps.

The sloping lines on Fig. 6 show the drop in pressure head when the system discharges the quantities of water shown in the above tabulation.

TABULATION FOR FIG. 7.

1	2	3	4	5	6	7	8	9	10	11	12	13
Pipe number.	Gallons per minute.	Assumed Diameter, inches.	Sum of resistances.	Length for $r = 1$.	Total length for resistances = products of columns 4 and 5.	Length of pipe.	Equivalent length = Sum of cols. 6 and 7.	L/H value	Head consumed = column 8 ÷ col. 9.	Total head consumed.	Head available.	Final Diameter, inches.
1	5	1	4.5	2.5	11.0	10	21	28	0.8	0.8	15.0	1
2	10	1	0.4	2.5	1.0	10	11	7	1.6	2.4	15.0	1
3	15	1¼	0.4	3.5	1.4	10	11	10	1.1	3.5	15.0	1
4	20	1¼	1.0	3.5	3.5	10	14	5	2.8	6.3	15.0	1¼
5	20	1½	2.0	4.5	9.0	11	20	14	1.4	7.7	15.0	1½
6	40	2	2.0	6.0	12.0	2	14	14	1.0	8.7	15.0	2
7	40	2	5.0	6.0	30.0	30	50	14	4.3	13.0	15.0	2
8	5	¾	5.5	2.0	11.0	12	23	7	3.3	3.3	27.0	¾
9	10	¾	0.4	2.0	0.8	10	11	1.6	7.0	10.3	27.0	¾
10	15	1	0.4	2.5	1.0	10	11	3	3.7	14.0	27.0	1
11	20	1	1.0	2.5	2.5	10	13	3	4.3	18.3	27.0	1
6	40	2	2.0	6.0	12.0	2	14	14	1.0	19.3	27.0	2
7	40	2	5.0	6.0	30.0	30	50	14	4.3	23.6	27.0	2

NOTE.—In practice when taps are opened a flow of water would ensue through the secondary return, if any, and would assist to supply the taps.

Column 4.

The numbers in Column No. 4 are intended to represent the sum of the " resistance ratios " of pipe-fittings and other resistances producing a change in the direction of the flow. The resistances shown in Column 4 are in this example more or less imaginary. Resistance ratios for valves, fittings, etc., are shown in Fig. 2.

Column 5.

Column No. 5 gives the length of straight pipe consuming the same head as a fitting having unit resistance or the length of pipe where $r = 1$. The length of pipe corresponding to $r = 1$ for various diameters of pipe is shown in Table II.

Column 6.

The numbers in Column 4 when multiplied by those in Column 5 give the length of piping consuming a head equivalent to the number of resistances shown in Column 4 and the product is inserted in Column 6.

Column 7.

Column No. 7 gives the net length of straight piping employed.

Column 8.

The numbers in Column No. 8 are derived by adding together those in Columns 6 and 7 and represent the equivalent length of pipe offering the same resistance to flow as the straight pipe itself plus that of the fittings thereon.

Column 9.

The numbers in Column No. 9 are derived as follows :—Pipe No. 1 is assumed to be ¾ in. diameter. For a flow of 5 gallons per minute by a ¾ in. pipe, Column 1, Table I gives a L/H value of 7. This number is entered under Column 9.

Column 10.

Dividing the equivalent length of pipe (Column 8) by the L/H value (Column 9) gives the head consumed by the appropriate pipe. For example : the equivalent length of pipe No. 1 is 23 ft. as shown in Column 8. Dividing 23 by the L/H value of 7 gives 3.3 as shown under Column 10.

Column 11.

This column gives the total head consumed. For example, the total head consumed by Pipes Nos. 1 and 2 is $3.3 + 1.6 = 4.9$ ft. as shown in Column 11 opposite Pipe No. 2.

The total head consumed by Pipes Nos. 1, 2, 3 and 4 is 3.3 + 1.6 + 1.4 + 4.7 = 11.0 ft. as shown in Column 11 opposite Pipe No. 4.

Column 12.

Column 12 gives the head available. In Fig. 5 the head available is given as 10 ft. The head consumed by the pipes numbered 1 to 4 is 11 ft. (see Column 11). As the calculated frictional head of the system exceeds that available some revision of pipe diameters is necessary. The effect of increasing the diameter of Pipe No. 1 from ¾ in. to 1 in. is shown under the word "Revisions."

For a 1 in. diameter pipe the head consumed (see Column 10) is 1 ft. as against 3.3 ft. for a ¾ in. diameter pipe. Adding the head of 1 ft. to the previous total of 11 ft. gives 12 ft. Deducting the head of 3.3 ft. for the ¾ in. pipe No. 1 gives a total head consumed of 8.7 ft., which is within the available head of 10 ft.

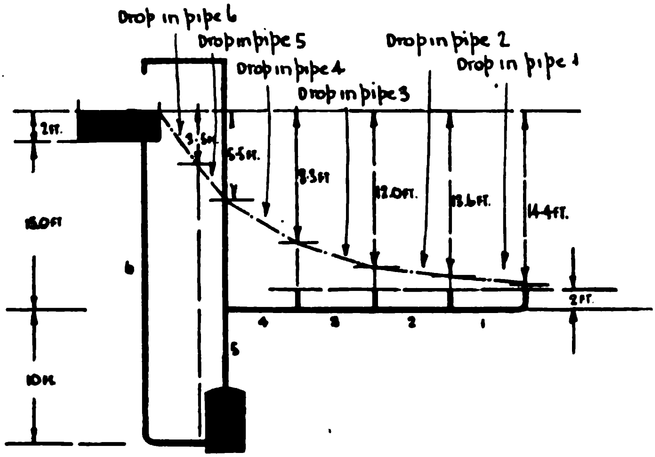


Fig. 6.

Pipes 5, 6 *and* 7.

Pipes Nos. 5, 6 and 7 are supplied by Pipe No. 4. The head consumed by Pipe No. 4 is 4.7 ft. (see Column 10). Deducting 4.7 from the total head of 20 ft., which is that actually available for pipes 5, 6 and 7, gives a net available head for these pipes of 15.3 ft. as shown in Column 12 opposite these pipes.

The total head consumed by pipes Nos. 5, 6 and 7 is 13.2 ft. as against an available head of 15.3 ft. and no revision is necessary.

Column 13.

The "Final diameters" are entered in Column 13.

The sloping lines in Fig. 5 indicate the calculated pressure drop when the system discharges the quantities of water shown in the Tabulation Column 2.

The diameters of pipes required in Figs. Nos. 6 and 7 are calculated similarly to those for Fig. 5, the same form of tabulation being employed.

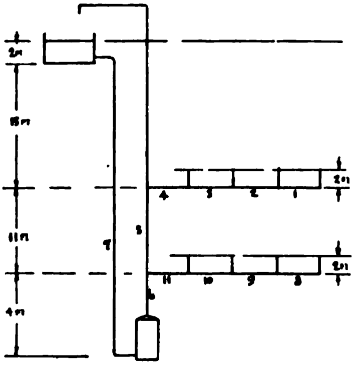


Fig. 7.

In conclusion, it may be once again emphasised that the fundamental principle involved in " pipe-sizing " is that the pipes must be of such a diameter as to ensure that the calculated frictional resistance of the system does not exceed the available head for the required outflow of water.

Building Research Station, Garston, Nr. Watford, Herts.

DECIBELS

By A. F. DUFTON, M.A., D.I.C.

In the discussion of a paper on "The Prevention of Vibration and Noise," read before the Institution in March, a simple definition of the *decibel* was asked for and the reply elicited was that the term had come over from the U.S.A. and that it was defined as "the minutest increase in sound which could be possibly detected by a human ear." Doubt was expressed as to the reliability of the decibel unit. In the circumstances it would seem desirable to point out that this definition and the definition which appears in the Guide of the American Society of Heating and Ventilating Engineers are incorrect. According to the *Guide* (1934), "One decibel is the power supply to a telephone receiver which will produce approximately the smallest change in volume of sound which the normal ear can detect."

The human ear is capable of appreciating differences in the intensity of sound over a remarkable range. If the intensity is measured in terms of the acoustic energy per unit volume of air, the loudest noise which the ear can hear is a million million times as great as the smallest difference which the ear can appreciate at all. The scale of intensities, in fact, is so vast as to be inconvenient and, in comparing two intensities, another unit is now used. This unit is the *bel*, the name being given in honour of Professor Alexander Graham Bell, the inventor of the telephone, who was born in Edinburgh in 1847.

If the energy per unit volume of air is ten times as great for one sound as it is for another, the intensity of the first sound is said to be one bel greater than that of the second. If it is one hundred times as great, two bels ; and a thousand times as great, three bels. It will be clear that if the intensity of one sound is one bel greater than that of a second which, in turn, is one bel greater than that of a third then the intensity of the first is two bels greater than that of the third. The scale is a very convenient one and the range covered by the human ear corresponds to approximately 12 bels or 120 *decibels*. The smaller unit, the decibel, one tenth of a bel, is conveniently used when intensities are quoted to fractions of a bel.

The human ear is most sensitive for the range of frequency between about 700 and 4,000 cycles per second : over this range the sensitivity is nearly uniform and sounds of equal intensity are judged as being of equal loudness. For this range of frequency, therefore, it is possible to express loudness upon a decibel scale, the zero on the scale being defined by the threshold of audibility of the " normal " human ear. For frequencies below 700 cycles, the ear is less sensitive to weak sounds and more sensitive to intense ones. The loudness, however, can conveniently be judged in terms of the equivalent loudness of a pure tone of 1,000 cycles.

DECIBEL SCALE OF STANDARD NOISES AND LOCALITIES.

Standard Rooms and Localities	Intensity above Threshold in Decibels	Common Noises
	120	(*Threshold of feeling.*)
Aeroplane cabin	110	Aeroplane engine at 10 ft.
Printing press room	100	Express train at 12 ft.
Tube train	90	Pneumatic drill at 20 ft.
Typing room	80	Motor horn at 20 ft.
Fairly noisy restaurant	70	Average busy street, London.
Ordinary room with conversation	60	Loud conversation.
Fairly quiet city office	50	Average quiet street, London.
Average suburban house-room	40	Quiet conversation.
Very quiet room	30	Average quiet street, Suburbs.
	20	Whisper, at 4 ft.
	10	Rustle of leaves in slight breeze.
	0	(*Threshold of Audibility.*)

The decibel scale of standard noises and localities shown above, is reproduced from a recent bulletin on " The Reduction of Noise in Buildings."[1] This bulletin gives also the following table of the amounts of existing noise which will be readily tolerated in different rooms and mentions that these values represent ideal conditions which are seldom realised in existing buildings.

---

[1] Building Research Bulletin No. 14, 1933, H.M. Stationery Office, 9*d*. net.

	Decibels
Studios for the recording of sound, as talking picture studios	6 to 8
Radio broadcasting studios	8 to 10
Hospitals	8 to 12
Music studios	10 to 15
Apartments, hotels and houses	10 to 20
Theatres, churches, auditoria, classrooms and libraries	12 to 24
Talking picture theatres	15 to 25
Private offices	20 to 30
Public offices, banking rooms, etc.	25 to 40

* * *

NEW BOOKS

MECHANICAL REFRIGERATION

The Heating, Piping and Air Conditioning Contractors National Association, U.S.A., have published, under the auspices of its Committee on Air Conditioning, the fourth part* of "Air Conditioning for Heating Contractors." This comprises five lessons, 11 to 15 inclusive, dealing with mechanical refrigeration.

The first lesson contains information on the theory of mechanical refrigeration by Mr. John Everetts, Jr. In the next lesson Mr. D. E. Perham deals with the broad and important subject of equipment. Its application and practice, by Mr. W. R. Rhoton, discusses quick freezing, oil cooling, ice making, cold storage, comfort cooling and industrial air conditioning. The subject of calculations is explained by Mr. George H. Dickerson, who confines his remarks to those types of installation which might be encountered by the heating contractor and gives practical methods rather than highly technical formulæ for calculating the necessary refrigeration capacities. The last lesson, by Mr. Charles E. Tolton, discusses the subject of safety precautions to be taken against toxic vapours which escapes from the system and concentrate to a dangerous degree in occupied rooms, and against the dangers of vapours exposed to open flame. The booklet, though dealing with American practice, contains very useful information and data on the theory and practice of mechanical refrigeration.

---

* Air Conditioning for Heating Contractors. Edited by S. Lewis Land. 7¼ in. by 4 in. 98 pp., 9 illus. Paper. Published by Heating, Piping & Air Conditioning Contractors National Association, 1250 Sixth Avenue, New York. 1934. Price $0.50

ABSTRACTS

What are Ions ?

Ionisation, as applied to air, is simply an indication of the electrostatic condition of the air. Normally, the minute physical systems or molecules of which the gases of the air are composed are electrostatically neutral. When these molecules, for one reason or another, become charged with negative or positive static electricity, they become ions, and are referred to as the " small " ions of the atmosphere.

The small ions are formed when certain types of radiation strike the molecules of the air. The energy of the radiation separates the positive and negative electricity in a neutral molecule of air, thus forming a pair of oppositely charged small ions. These radiations emanate principally from radio-active substances in the soil and the air, although an appreciable portion is attributable to the little-understood cosmic rays.

Atmospheric air, especially that in the neighbourhood of densely populated areas, carries in suspension at all times minute particles of solid matter called condensation nuclei. These condensation nuclei, so called because atmospheric moisture condenses upon them to form rain drops, originate from smoke from chimneys, exhaust gases of internal combustion engines, exhaled air from the lungs of animals, and a number of other sources. Normally, these nuclei are neutral electrostatically, but when a small ion makes contact with one of them, as it frequently does, the small ion gives up its charge to the larger particle of solid matter, and it becomes a " large " ion of the atmosphere.

This process goes on continuously in both directions, for when a positively charged small or large ion makes contact with a negatively charged small or large ion, the charges of opposite polarity balance, and the ion no longer exists. In other words, ions are constantly coming into being in the atmosphere, and are constantly being neutralised or removed by combining with ions of opposite polarity.

The number of ions in the air is found to be a maximum in the early morning and a minimum in the late afternoon. These regular and systematic daily variations in the number of ions take place at all places, but the variations for one locality are not usually identical with those in another. (*Heating and Ventilating*, April 1934.)

The Kata-Thermometer.

The Kata-thermometer, invented by Dr. Leonard Hill, is used very considerably as a comfort meter. It consists of an alcohol thermometer graduated from 95° F. to 100° F., and it may be used with either wet or dry bulb. It will be noted that the temperature through which it is graduated is approximately that of the human body, and the method of use is as follows. The thermometer is warmed by immersion in warm water to a temperature above 100° F.; the bulb is then dried thoroughly for dry Kata readings, and the time noted by a stop-watch for the temperature to fall from 100° F. to 95° F. In the case of wet Kata readings a cotton lisle wick is fitted around the bulb and the process repeated, all surplus moisture being lightly brushed away after removal from the water in which it was heated. Each instrument has a factor F engraved on the stem, and by dividing this factor by the time of cooling in seconds, the Kata cooling power is obtained in millicalories per sq. cm. per second. For sedentary workers, the dry Kata cooling power should not be below 6, and the wet Kata cooling power not below 18. It should be noted that the dry Kata gives the cooling power by radiation and convection, and the wet Kata by radiation, convection and evaporation. (Norman Wignall, *The Heating and Ventilating Engineer*, March 1934.)

Refrigeration for Air Conditioning.

The latest development in refrigeration is the steam-jet refrigeration machine which uses water evaporated under a high vacuum to produce temperatures as low as 45 to 50° F., which is all that is needed in the usual air-conditioning system for summer. This evaporation is done under an extremely high vacuum produced by steam jets.

The steam-jet machine may be run off on a steam pressure as low as 10 lb. It requires no licensed engineer to operate, has no moving parts and requires the purchase of no refrigerant. It is useless for refrigerating cold-storage rooms owing to the temperature being too high, but it is entirely adequate for air-conditioning work.

The amount of steam used is about double at a 10-lb. pressure of what it is at a 100-lb. pressure, and where buildings are supplied with street steam at good pressure, the use of these machines is very satisfactory.

TABLE A.

Refrigerant used.	Horsepower of Motor per ton of capacity
Ammonia	1
Carbon dioxide	1⅞
Sulphur dioxide	1
*Steam jet	0
Freon	0⅞
Menthol chloride	1

* 70 pounds of steam at a 10-pound pressure down to 35 pounds of steam at a 100-pound pressure per ton of refrigeration when cooling water to 45 degrees Fahrenheit.

The power required per ton to operate refrigeration machines of various types and employing various refrigerants is roughly as shown in Table A for ordinary air-conditioning work. (Harold L. Alt, *Plumbing and Heating Trade Journal*, April 1934.)

Points for Oil Burner Salesmen.

It is sometimes of interest and advantage for the dealer or salesman to know certain other technical information, which oftentimes comes into use. I, by no means, suggest the use of these terms and phrases as a steady diet for the salesman, but where they do come in handy they are as welcome as a port in a storm. A salesman should know—that a desirable stack temperature is less than 400° F. —that a proper draught over a fire is 0.02 in. to 0.05 in.—that a desirable draught in the breeching is from 0.12 to 0.15 in.—that a domestic job is working satisfactorily if it has a CO$_2$ of 11 per cent., and that this fire will be slightly smoky—that CO$_2$ means the flue gas analysis in its relationship to the excess air—

That a 15% CO$_2$ represents No fuel loss
That a 14% CO$_2$ represents 0.83% fuel loss
That a 13% CO$_2$ represents 1.78% fuel loss
That a 12% CO$_2$ represents 2.89% fuel loss
That a 11% CO$_2$ represents 4.21% fuel loss
That a 10% CO$_2$ represents 5.74% fuel loss
That a 9% CO$_2$ represents 7.67% fuel loss
That a 8% CO$_2$ represents 10.08% fuel loss
That a 7% CO$_2$ represents 13.14% fuel loss
That a 6% CO$_2$ represents 17.25% fuel loss
That a 5% CO$_2$ represents 23.0 % fuel loss
That a 4% CO$_2$ represents 31.62% fuel loss
That a 3% CO$_2$ represents 46.05% fuel loss
That a 2% CO$_2$ represents 74.70% fuel loss

that a gallon of oil is capable of heating 350 sq. ft. of steam, total tax, using oil of 142,000 B.T.U. contents and considering a boiler efficiency of 60 per cent.—that it requires approximately 100 sq. in. of deck area to each gallon of oil to be burned—that it requires approximately 3 cu. ft. of combustion space for each gallon to be burned—that the unit of heat is a B.T.U. and that it is the amount of heat required to change the temperature of 1 lb. of water 1° F. —that a degree day is a day in which the average inside temperature is 1° F. higher than the average outside temperature. (Dayle G. Malone, *Domestic Engineering*, April 1934.)

HEATING AND VENTILATING INDEX

Comfort. 613.18

What is this Thing called "Comfort?" A. P. Kratz. 3 pp., 5 illus. Explaining how comfort chart was compiled and how windows and walls affect comfort : *American Artisan*, March 1934.

Cooling. 697.96

A Cooling Data Sheet. 2½ pp. Discussing formulæ required for cooling installations, coefficients, water, ice and refrigeration : *American Artisan*, March 1934.

Hot-Water Heating. 697.42

Chauffages a Eau Chaude Défectueux. B. Guillot. 4pp., 11 illus. Dealing with possible causes of defects in hot-water heating apparatus : *La Couverture-Plomberie*, March 1934.

Radiators. 536.2, 697.4

Radiation. Leslie Rayner. 2½ pp., 10 illus. Dealing with heat transmission from radiators and effect of enclosures : *The Plumber*, April 2nd, 1934.

Drying. 634.9

Principles of Drying. C. W. Ulett. 5½ pp., 3 illus. Dealing with properties of steam, blowers and exhausters, theoretical and practical comparisons : *Heating and Ventilating Engineer*, March 1934.

Oil-Burners. 621.182.23

Automatic Oil Burner Installations. 2½ pp. Describing method of calculating oil consumption : *Heating and Ventilating Engineer*, March 1934.

Ventilation. 697.9

Students' Text Book of Heating and Ventilation. Norman Wignall. Discussing ventilation requirements : temperature, humidity and air motion : *Heating and Ventilating Engineer*, March 1934.

Steam Generation. 621.18

Air Leakage in Steam Units. W. S. Patterson. 1½ pp. Dealing with air infiltration ; forced draught, boiler settings, air heaters and importance of air infiltration : *The Fuel Economist*, March 1934.

Fuel. 621.182.22

Evaluation of Coals for Boiler Firing. Donald Andrews. 2½ pp. Dealing with choice of fuels, volatile matter, coking properties, ash, moisture, sulphur, size, calorific value and cost : *The Power Engineer*, April 1934.

Humidity. 533·3

How Accurate are Humidity Calculations. N. R. Sparks. 3 pp., 5 illus. Describing investigation into accuracy of charts giving air properties and checking errors : *Heating and Ventilating*, April 1934

Air Conditioning. 697.96

Air Conditioning in Baking Plants. W. W. Reece. 4 pp., 5 illus. Dealing with material storage, mixing, make-up department, proofing and bread cooling : *Heating and Ventilating*, April 1934.

Ducts. 697

Temperature Drop of Air in Ducts. J. Donald Kroeker. 3½ pp., 3 illus. Describing charts for calculating temperature loss from ventilating ducts : *Heating and Ventilating*, April 1934.

Air Cooling. 697.96

Rule for Figuring Cooling Effect of Extended Surface. Chester J. Scanlan. 3½ pp., 5 illus. Describing rule of capacity of extended surface cooler where air velocity and refrigerant is proportional to heat content of entering air, with examples of application and charts : *Heating and Ventilating*, April 1934.

Mechanical Stokers. 621.183.6

Stoker Firing Low Pressure Heating Plants. Clint E. Beery. 6 pp., 3 illus. Dealing with high and low-pressure heating systems, stoker and boiler design, screw-feed and ram-type, coal for automatic cone burners, fly-ash and its correction : *Heating, Piping and Air Conditioning*, April 1934.

Refrigeration. 697.96, 621.565

Water-Vapour Refrigeration for Air Conditioning. Paul Bancel. 4 pp., 6 illus. Dealing with development of the centrifugal compressor unit, horsepower requirements, operating characteristics, reserve capacity and applications of water-vapour refrigeration : *Heating, Piping and Air Conditioning*, April 1934.

Air Conditioning. 613.11

Air Conditioning in its Relation to Human Welfare. C. A. Mills. 5 pp., 6 illus. Describing study of relation of climatic and weather environment to health and general welfare : *Heating, Piping and Air Conditioning*, April 1934.

Hot-Water Heating. 697.4

Heating Buildings with Hot Water. Benj. F. Burt and Samuel R. Lewis. 5 pp., 3 illus. Discussing heating by hot water and pointing out its advantages : *Heating, Piping and Air Conditioning*, April 1934.

Exhaust Steam. 697.53

Exhaust Steam Utilisation Offers Economy to Plants and Buildings. Perry West. 3 pp., 2 illus. Dealing with heating requirements of buildings and use of exhaust steam for water heating, drying, process and air conditioning : *Heating, Piping and Air Conditioning*, April 1934.

Air Conditioning. 697.96

A Proving Home for Air Conditioning Investigations. Elliott Harrington and Leon A. Mears. 8 pp., 12 illus. Describing plant and investigations of air conditioning under actual living conditions. *Heating, Piping and Air Conditioning*, April 1934.

Hot-Water Heating. 697.4

Etude de la Variation des Débits de la Tuyauterie en Fonction de la Variation des Charges. J. Quint. 5 pp, 3 illus. Study of the variation of the delivery of piping in relation to the variation of head : *Chauffage-Ventilation*, March 1934.

Air Conditioning. 697.96

Summer Air Conditioning. Harold L. Alt. 3½ pp., 5 illus. Discussing reduction of humidity and air cooling : *Plumbing and Heating Trade Journal*, April 1934.

Heat Transfer. 536.2

Effect of Moisture on Heat Transfer. Siegfried Ruppricht. 9½ pp., 11 illus. Dealing with the theory of heat transfer in unit coolers, investigation and results : *Refrigerating Engineering*, April 1934

Bakeries. 697.96

Problems in Bakery Conditioning. W. W. Reece. 3 pp., 2 illus. Dealing with fermentation control, proofing control and conditioned bread cooling : *Refrigerating Engineering*, April 1934.

Air Cooling. 697.96

Performance of Extended Cooling Surfaces. Chester J. Scanlan 2¾ pp., 4 illus. Describing how to state and compute the transfer of sensible and latent heat, with test data and examples : *Refrigerating Engineering*, April 1934.

Garages. 725.38

How to Heat the Detached Garage. Harold L. Alt. 3½ pp., 8 illus. Describing methods of warming garages from house heating system : *Domestic Engineering*, April 1934.

Insulation. 536.2

Insulation for the Modern Home. A. P. Kratz. 3 pp., 3 illus. Dealing with effects of insulation on the heat transmission of buildings : *Domestic Engineering*, April 1934.

INSTITUTION OF HEATING AND VENTILATING ENGINEERS

REPORT

SUMMER SPECIAL MEETING, HASTINGS, JUNE 19th, 1934

THE Summer Special Meeting of the Institution was held at the Queen's Hotel, Hastings, on June 19th, 1934, the President, Mr. R. Comyn Ching, in the Chair.

There were about 85 present. The following signed the attendance register :—Messrs. Geo. H. Bennett, Geo. A. Pullen, G. Nelson Haden, W. H. Becket, R. C. Ching, F. M. H. Taylor, F. Clegg, A. B. Potterton, Robt. E. Herring, Edgar Herring, T. W. Dunkley, J. G. Clark, G. W. Fowle, W. Mumford Bailey, O. Meikle, G. L. Copping, A. F. Bundey, T. E. Barnes, W. G. Case, A. J. Assheton, S. Adams, C. B. Jackson, E. B. Darby, A. J. H. Binns, J. W. Stitson, W. W. Nobbs, Harry Merrin, J. W. Cooling, C. A. Masterman, T. G. Noble, S. J. Warrell, L. W. Andrew, F. A. Norris, Walter Scott, G. H. Rees, E. Brooks, L. J. Fowler, T. F. C. Potterton, Alcwyn A. Jones, and H. B. Watt (Secretary) (London) ; Frank Biggin (Sheffield) ; B. R. Wingfield (West Drayton) ; John Binns (Bradford) ; Geo. Crispin (Bristol) ; A. S. Naylor, Sam Naylor, Sam Fox (Halifax) ; Ian McVean, W. Newbold (Beeston) ; James Elliott, H. W. S. Martin, Walter Yates (Manchester) ; Samuel Greenwood (Hendon) ; W. Nelson Haden, C. Ingham Haden (Trowbridge) ; A. Allen (Stourbridge) ; E. R. Jones (Bromsgrove) ; Geo. J. Belgrove (New Malden) ; L. Broadbridge (Brighton) ; H. B. Blackman (Hastings) ; R. E. Otter, W. L. Gee (Birmingham) ; F. H. Eldershaw (Speldhurst) ; E. G. Hill, S. Thomson (Hull) ; W. A. Young (Bromley) ; E. G. Phillips (Nottingham) ; Arthur Roberts (Liverpool) ; A. E. Johnson (Ipswich) ; F. G. Alden (Oxford) ; E. L. Maiden (Hendon) ; and the following visitors : Walter T. Dunn (Hastings) ; C. Redbourn (Brighton) ; Mr. and Mrs. Dufton (Garston) ; E. J. Laidlaw, C. F. Wilson (London) ; F. W. Leach (Bristol) ; R. Goodinge (Banstead).

WELCOME BY THE MAYOR.

The President (Mr. Ching), in opening the proceedings, expressed his gratification at seeing so large a number at the Summer Meeting. He thought the Institution had been very fortunate in its choice of a locality, and the weather also was good to them. A large programme had been arranged, and he impressed the desirability of brevity in speeches upon members. He then proceeded to

INSTITUTION OF HEATING AND VENTILATING ENGINEERS.

SUMMER MEETING, HASTINGS, 1934

introduce the Mayor, who, although busily engaged in a series of conferences, had found time to come and bid them welcome. He congratulated the Mayor on the wonderful improvements which had taken place in recent years in the town of Hastings. He himself had known it for a good many years, and at one time it was rather " dead and alive " ; it was now one of the brightest seaside resorts in the country. On a similar occasion to this a few days ago the Mayor had referred to the long history of Hastings, saying that it dated back to time immemorial, and that its Charter was granted in the reign of Queen Elizabeth. But to most of them the name of the town recalled that of a decisive battle at a much earlier period in English history. He thanked the Mayor and the Town Council for their hospitality in affording facilities to the members to participate in the various municipal entertainments and conveniences during their stay. Already many of them had made use of the wonderful swimming-pool and baths, and later they would have an opportunity of enjoying the bowling greens and tennis courts.

The Mayor (Alderman Henry Burden, J.P.), said that it was a very great relief to his mind to hear the President say that long speeches were not expected. He had suffered from long speeches himself, and he did not want to inflict another on those present. But he did wish simply to express his sincere welcome to the town of Hastings. It was quite a common thing now for people who had not been to Hastings for a few years to express, as the President had just done, astonishment at what had been achieved during the last decade or two. Hastings had been brought up-to-date. On a memorable occasion a few weeks ago, when the Freedom of the Borough was accorded to Lord Reading, the speaker referred to the glories of the town in the distant past ; that was appropriate then because the occasion was essentially a Cinque Port function. But the Hastings of the past was not to be compared with the Hastings of the present day. As most of those present knew, some £3,000,000 had been spent on improvements during the last ten years, and he believed it would be the opinion of the visitors when they saw what had been done that the money had been spent wisely. If they were interested in bowls they would find there some of the finest facilities for that game that there were in England.

He offered his good wishes for the success of the conference. The Institution was engaged in the study of some very interesting problems which contributed not a little to the comfort of the community. It was common to hear a vast amount of grumbling and complaint with regard to the heating and ventilating of public buildings, and in that aspect he did not doubt that many scientific problems still awaited solution. If it could be said that during the conference at Hastings the problem of ventilation of public buildings had been solved, then Hastings again would make history. He hoped that all the visitors would carry away the pleasantest impression, and would tell their friends that the Hastings of to-day was well worth visiting.

Mr. W. E. Fretwell proposed a vote of thanks to the Mayor for sparing the time in his busy life to give a welcome to the visitors. He believed that that very day a Ministry of Health inquiry was being held in the town which necessitated his attendance. It was very probable that much would be heard during the meeting about problems of ventilation, but when they got to such a place as Hastings they were more concerned with the air outside buildings than inside. He called upon those present to express their thanks to the Mayor for his welcome.

The vote of thanks was accorded with Kentish fire, during which the Mayor withdrew.

MESSAGE FROM NEW YORK.

The President read a letter which had been received from the American Society of Heating and Ventilating Engineers. It read as follows : " Dear Mr. Ching, The officers and members of the American Society of Heating and Ventilating Engineers send greetings to the members of your Institution and hope that your deliberations during the Summer Meeting will be interesting and profitable. The semi-Annual Meeting dates of the two organisations are overlapping, and we take pleasure in sending an advance copy of our programme which we hope will prove of interest. We shall look forward also with interest for a report of your meeting in the next issue of your *Journal*. With best wishes for a most successful meeting. (Signed) A. V. Hutchinson (Secretary)."

The President said that it was very kind of their American colleagues to send such greetings, and he suggested that a cable be sent to New York from that meeting wishing them every happiness and prosperity.

This was agreed to unanimously.

MINUTES.

The Secretary (Mr. H. B. Watt) read the minutes of the Ordinary Meeting held in London on February 14th, 1934, which were confirmed and signed.

ELECTION OF NEW MEMBERS.

The President said the next business was the election of new members, and that the names to be submitted had been carefully considered by the Scrutineers Committee, and also by the Council meeting held on the previous day, and they were all approved.

The Secretary read the names of the applicants recommended by the Council for election as Members, Associates, Associate Members, Operative Associates, and Graduates.

MEMBERS.

Arthur Webley Beaven .. .. 64 Victoria Street, Westminster, S.W.1.
John Walter Leslie Beaven .. County Buildings, Westgate Street, Gloucester.

TRANSFER FROM ASSOCIATE MEMBER TO MEMBER.

Sidney Frederick Greenland .. 71 Arodene Road, Brixton, S.W. 2.

ASSOCIATES.

Jonas Sharp Birkett .. .. Messrs. Binns & Speight Ltd., Crown Boiler Works, Bradford.
Francis Harry Field .. .. 21 Raleigh Avenue, Wallington, Surrey.
James Jamieson .. .. .. Messrs. Bastian & Allen Ltd., 62 Robertson Street, Glasgow.
Robert Elias Lloyd-Owen .. 18 Wilson Crescent, Wimbledon, S.W.19.

ASSOCIATE MEMBERS.

Stanley Wilfred Albert Brown .. "Kirtlands," 53 Lindon Drive, Alvaston, Derby.
Herman Charles Bullock .. .. 32 Fern Road, Erdington, Birmingham.
Sidney Oliver Etherden .. .. 174 Osmaston Park Road, Derby.
Wilfrid Robert Akerman Hampton c/o Messrs. The British Fan & Electric Company, 21 Mt. Pleasant, Rosebery Avenue, London, W.C.1.
Harold Edward Fell Heath .. 16 Corndale Road, Mossley Hill, Liverpool.
Edgar Kershaw .. .. .. 14 Hapton Avenue, Stretford, Manchester.
George Wallace Peach .. .. 62 Elms Road, Stoneygate, Leicester
Alfred Edward Watson .. .. 37 Courtenay Road, Worcester Park, Surrey.

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER.

George Frederick Wattears	8 Trafalgar Square, Chelsea, London, S.W.3.

OPERATIVE ASSOCIATES.

William Hardingham	21 Burleigh Road, Stretford, Manchester.
William John Neale	11 Hay Green Lane, Bournville, Birmingham.

GRADUATES.

George Coase	44 Gleden Street, Bradford Road, Manchester.
Harry William Heath	41 Ridgeway Road, Isleworth, Middlesex.
Roland Bryon Heywood	11 Manor Way, Harrow, Middlesex.
Charles Frederick Morgan	7 St. Stephen's Road, Highfields, Leicester.
Thomas Henry Wakeling	10 Baden Road, Stoughton, Guildford, Surrey.
John Laurence Waller	41 Maison Dieu Road, Dover, Kent.
Dennis Henry Joseph White	44 Grove Park Avenue, South Chingford, E.4.

Mr. Alcwyn A. Jones said that it was very gratifying to see that the membership of the Institution was still increasing, and that the stiffening up of the examinations had not proved to be a deterrent to those wishing to enter the Institution. He proposed that the candidates in the various grades be elected *en bloc.*

Mr. S. Naylor seconded, and this was agreed to unanimously.

PROPOSED AWARD OF SCHOLARSHIP.

Mr. W. E. Fretwell, who was invited by the President to say a few words on the proposed new scholarship award, said that the President had been deeply interested in the technical education of heating engineer students for many years, and the present proposal was really his " baby." The Council on the previous day had discussed this matter very fully and recommended that one scholarship per year should be awarded to an evening-class student, preferably of the operative section. The value of the scholarship would be 5 guineas per year for three years—a total of 15 guineas. There would be one scholarship awarded each year, carrying with it a value of 15 guineas tenable for three years. It was suggested that the award should be decided by the Examination Committee, which would, of course. report to the Council. The award would be determined very largely by the report of the teachers and principals on the work of the student in the technical classes at the various Institutes. It was hoped by that means to encourage students to increase their technical efficiency. The amount which was to be awarded was not great, but it was hoped that it would help the student to pay his fees and provide text books, and it would, at the same time, encourage him to further endeavours. He hoped the proposal would receive the unanimous approval of the members. The aim of their body was essentially educational, and they could not do better than expend some of their funds in this direction.

The President said that he did not think it was necessary to have a resolution on the subject from that meeting, but he hoped that members would testify by applause their general approval of the proposal.

The meeting signified its warm approval in the way suggested by the President.

REPORTS OF COMMITTEES.

Examination Committee.

Mr. J. W. Cooling said that the President had asked him to make a brief statement on the entrance examinations. He wished to inform the members that the examination syllabus had been considerably revised and was now printed and available to intending candidates. He believed that the new syllabus would make things much clearer for candidates than in the past. It had also been decided that the old examination papers would be available for candidates in order to give them some better idea of the character of the examination.

He then proceeded to give some details of the last examination, which was held in London, Birmingham, and Liverpool. There were eleven Graduate candidates, of whom five passed, and there were seven candidates for Associate Membership, of whom six passed, one of them with honours.

The Examination Committee hoped that the members would encourage their friends who were heating and ventilating engineers to come along and sit for the examinations. It was intended that examinations should be rather more difficult than in the past, and that the standard of the Institution in this respect should be raised ; but, at the same time, it was felt that with the revised syllabus and the fact that the old examination papers were being made available to the candidate, the candidate would have rather more confidence in entering.

The President said that he thought that Mr. Cooling and his Committee were doing some quite excellent work on behalf of the Institution, and work, moreover, which involved a large amount of highly technical detail. They thanked Mr. Cooling for the great work he was doing on their behalf.

Technical Education Committee.

Mr. Walter Yates said that the matter which the President had asked him to bring forward was perhaps of more importance to the provincial members than to the London members. There had been some complaint for some time past that London members got many more benefits than did members in the provinces. Many more meetings of the Institution were held in London than elsewhere, and these meetings, of course, the provincial member, owing to the necessary expenditure of time and money, could not always attend. Mr. E. G. Phillips, from Nottingham, had, therefore, suggested that it was desirable to form Local Branches in various parts of the country, and that in the first instance a Local Branch should be formed in the East Midland area. The Council had considered the matter and remitted it to the Technical Education Committee, by whom it had been very carefully explored. Mr. Phillips himself had been co-opted on the Committee for that purpose. The Committee had reported on the previous day to the Council, and the Council had decided to form immediately this Local Branch in the East Midlands, comprising five or six counties. It had been also decided to form special rules and regulations for the conduct of the Local Branches, and rather than wait for another Council meeting to pass the rules before anything could be done, it had been decided that Mr. Phillips should be asked to undertake at once the formation of a Local Branch for the East Midlands. The Branch would be a real and full Branch of the Institution in that area, and any meetings called would be open to every member of the Institution whatever his grade. Members would be aware that there were already four branches in different parts of the country, of the Associate Members and Graduates Section, but those meetings members were not expected to attend, and it was those members who had felt that something more should be done. It was, therefore, the intention that each centre as it was formed should have a full Branch—that is to say, should have more or less the full authority of the parent Institution. It was also intended that when Branches were formed in the centres in which already Associate Members and Graduates had their existing organisation, the latter should form part of the full Branch. In other words, the conduct of affairs would be more or less a duplication locally of that at headquarters. The first Branch, as he had stated, would be formed in the East Midlands, and if that was the success which it was hoped it would be, Branches would be formed in other areas. In fact, it was hoped to divide the whole country into suitable areas, for each of which eventually a Branch would be formed. He thought that this was a piece of work much desired, and well-worth doing, and that the decision of the Council would be welcomed by every member.

The President said that the formation of Local Branches was quite a new thing for the Institution, and he felt that it would add to its prestige and would also help to bring in quite a large number of new members. He wished to supplement in one respect what Mr. Yates had said, namely, that it was fully intended that the new Branches should not interfere in any way with the activities of the Associate Members and Graduates Section. That Section had worked very well indeed, and had been of great value to the Institution as a whole. It was intended that they should function in just the same way as they functioned now, and he was sure that if a new Branch were formed in a locality it would have loyal support from every grade of membership. On this matter, also, he did not think it necessary to take a vote of the meeting, but if any member had any suggestions to make they would be very welcome.

Mr. James Elliott said that he was glad to notice that this matter was receiving the approval of the members. He had himself taken particular interest in the formation of local branches of the Associate Members and Graduates Section, and he had felt very jealous indeed lest any new steps that might be taken should in any way jeopardise the organisations already in existence. The matter had been discussed by the Council at some length, and he now felt sure that the organisations already existing would be thoroughly safeguarded. The more local branches there were in the country the better it would be for the Institution.

A Member said that he thought the thanks of the members were due to Mr. Phillips, of Nottingham, for the memorandum which he had brought before the Education Committee suggesting this new departure, and also for his promise to father the new Branch which was to be started in his area.

The Benevolent Fund Committee.

Mr. W. W. Nobbs said that he had been asked to say a few words on the Benevolent Fund. This innovation was entirely due to the efforts of the President, who drafted the scheme on his own before asking the Council to give it sympathetic consideration. The Council appointed a special Committee to consider the President's suggestions and prepare a draft Memorandum and Articles of Association. The Committee had prepared the draft and it had been submitted to and approved by the Council on the previous day. The next step would be to obtain the approval of the Board of Trade, when they would be in a position to print particulars for the information of members. He hoped that the creation of this Fund would prominently mark the year of Mr. Ching's Presidency and he felt sure that it was one with which every member would be in full sympathy.

The President said that at the last Ordinary Meeting, held in London in February, he had briefly sketched out this proposal for the formation of a Fund. An incorporated company, really like a limited liability company, but with permission to omit the word "limited" from its title, would be formed. He was anxious to make it clear that this did not mean that it would involve the Institution in any expense at all, except the comparatively minor expense of the fees for getting out the company papers. The Council agreed on the previous day to the formation of the Benevolent Fund, and to all intents and purposes the Fund was now in being. The minimum subscription which was suggested for membership of the Benevolent Fund was 5s. a year, although, of course, they would be happy to receive larger sums from anyone who wanted to give more. They would welcome also any donations to the Fund apart from annual subscriptions. He was himself proposing to start the Fund with a donation of 50 guineas, and Mr. Fretwell had also signified that he would start with a donation of 25 guineas. He hoped that the Fund would be of value to the Institution and give it an opportunity of relieving necessitous cases of their brethren in distress when such came forward. It must be understood that there would be no compulsion on the part of the Benevolent Fund to distribute the money in any particular way; it would be entirely in the hands of the Committee to distribute what funds were available in practically any way they thought right. The control and distribution of the Fund would be in their hands, and there would be no prescriptive right of any member to a claim on the Fund. It was entirely voluntary on both sides.

In reply to a question as to whether subscriptions should be limited to members or should be invited from firms which had members on their staff, the President said that he thought the intention was that the benefits of the Benevolent Fund should be confined to those who were actually members of the Institution, of whatever grade, whether Members, Associates, or Graduates, but so far as donations were concerned, they need not of necessity be limited to members of the Institution, If anybody outside the Institution cared to subscribe or donate anything towards the Benevolent Fund they would be only too pleased to receive it. At the same time he wished to impress on members that it would not be right or consistent with the dignity of the Institution if anyone went around asking outside people for donations. As President he would very strongly object to that, but otherwise any donation that anyone would like to give would be very acceptable.

Research Committee.

Mr. W. W. Nobbs reported that following the meeting held on February 6th last between representatives of the Institution and the Departmental Committee, when it was agreed to proceed with the construction of the Experimental House subject to preliminary tests to determine the character and construction of the warming and cooling surfaces, arrangements were put in hand to provide and fit up the plant for carrying out the tests.

Preliminary experiments with panels containing the warming and cooling coils had, so far, not been satisfactory as with two forms of construction tried the surface rendering crumbled or became detached or other faults became evident after a certain amount of intermittent warming and cooling to below the freezing point.

Further experiments were proceeding, but the Committee was not yet in a position to draw any definite conclusions.

The President said that their thanks were due to Mr. Nobbs for the work that he was doing in the matter of research. He knew that it must take up quite a large amount of his time, and as engineers the members realised that it was no easy matter to carry through research of this kind because of the many unexpected difficulties which were encountered. It was a matter for careful investigation, and some people might occasionally become a little impatient and feel that the thing was not going on as quickly as it should. When the difficulties involved were realised, however, they would appreciate that it was no easy matter.

The Journal Committee.

Mr. Sam Fox reported for the Journal Committee, saying that he thought all was going on well and smoothly with the *Journal*, though there was very little of importance to report. He did not wish it to be understood that the Committee considered the *Journal* to be perfect ; far from it, but any improvement in the *Journal* must almost necessarily come from the members themselves, and for that reason he appealed to them to take a keen interest in it and to do all they could to improve it by sending in suggestions or communications of any kind. The Committee would be only too glad to look into any such suggestions, and if they considered them for the benefit of the *Journal*, to adopt them. He added that a little while ago arrangements were made to provide members with a binding cover for the year's *Journals*. This offer had not been taken up very widely, and there were still a large number of covers in hand. Members who wished for a cover should write to the Secretary.

The President recalled that it was Mr. Fox who, during his year of office as President, inaugurated the *Journal*. He was a prime mover in its foundation, and their thanks were due to him for keeping the thing going. It was a valuable asset to the Institution.

The Publicity Committee.

Mr. Alcwyn A. Jones said that the Publicity Committee was anxious to receive offers of papers for the forthcoming session. The Institution could not exist unless members were willing to present papers at the various meetings, and his committee was now hard at work trying to fix up a programme for the main meetings. The Honorary Secretaries of the Associate Members and Graduates Section were also anxious to receive offers of papers for their meetings. He hoped that members present would send such offers to the Publicity Committee or to the secretaries of the Associate Members and Graduates Section as the case might be, so that a good programme of papers could be arranged for the session 1934-35.

Mr. W. E. Fretwell desired to add a few words to what Mr. Jones had said. He appealed to all members to do their best to get more papers for the next year. He was personally a little anxious about the matter because he might be called upon after the end of the year to be responsible for this matter, and he hoped that members would not let him down.

The President then called upon Mr. A. F. Dufton, M.A., D.I.C., to read his paper on "Some Heating and Ventilating Problems," which was accompanied by a number of interesting lantern slides.

SOME HEATING AND VENTILATING PROBLEMS

BY A. F. DUFTON, M.A., D.I.C.

SUMMER SPECIAL MEETING, HASTINGS, JUNE 19th, 1934

SOME ten months ago, when I had the honour of receiving an invitation to present a paper upon this occasion, I asked myself what would be an acceptable topic for discussion and without any difficulty at all decided that, as the *Journal* shows each month a picture of the Building Research Station, it would not be inappropriate to tell you something about building research, paying attention to those aspects of particular interest to heating and ventilating engineers. I proposed, therefore, to take as my subject " Some Aspects of Building Research " and felt quite happy until I found that the Director of Building Research wished to reserve this topic for another occasion.

Now this put me in a quandary. I could not very well promise to talk to you about all the odds and ends of heating and ventilating research which might accrue, because I knew full well that the able Editor of the *Journal* would surely extract them from me and take all the cream. I promised, therefore, to speak on " Some Heating and Ventilating Problems," thinking that I might well discuss the problems connected with the elimination of noise and the prevention of vibration. Alas for my hopes ! Mr. Robert Grey has forestalled me with his paper in March.

This preamble is just to explain that I do not feel bound by the title of my paper, and to let you know that I am going to talk about smoky chimneys. These are real heating and ventilating problems.

Now by smoky chimneys, I do not mean chimneys from the top of which smoke issues. These are quite another problem which, although a very serious one, can be satisfactorily dealt with. My own chimneys do not smoke in this way because I burn anthracite, coke and gas, three smokeless fuels. Soft coal is the chief smoke producer and has been creating a nuisance for more than six centuries. We are told that in 1257, Queen Eleanor was obliged to leave Nottingham owing to the smoke of the sea coals, and I understand that there is extant, in the records of one of Queen Elizabeth's parliaments, a motion made by a member, reciting, " That many dyers, brewers, smiths, and other artificers of London, had of late taken to the use of pitcoal for their fires, instead of wood, which filled the air with noxious vapours and smoke, very prejudicial to the health, particularly of persons coming out of the country ;

and therefore moving that a law might pass to prohibit the use of such fuel (at least during the session of parliament) by those artificers."

But to come to the other variety of smoky chimney, the chimney which does not properly remove the gaseous products of combustion of a fire.

In illustration of the action of a chimney, I would like here to read to you a short extract from a lecture by Professor Thomas Young, given at the Royal Institution early last century.[1]

"The operation of heat affords us also a very effectual mode of ventilation. Its action upon the air at common temperatures occasions an expansion of about 1/500 for every degree that Fahrenheit's thermometer is raised; the air becomes in the same proportion lighter, and the fluid below it is consequently relieved from a part of its weight: the pressure of the surrounding atmosphere, therefore, preponderates, and the lighter column is forced upwards. When the shaft of a mine communicates with the external air at two different heights, there is generally a sufficient ventilation from the difference of the temperatures of the air in the shaft, and of the surrounding atmosphere: for the temperature of the earth is nearly invariable, it therefore causes the air in the shaft to be warmer in winter than the external air, and colder in summer; so that there is a current upwards in winter, and downwards in summer; and in the more temperate seasons, the alternations take place in the course of the day and night. For a similar reason, there is often a current down a common chimney in summer; but when the fire is burning, the whole air of the chimney is heated, and ascends the more rapidly as the height is greater. It would be easy, from the principles of hydraulics, if the length of the chimney and the mean temperature of the air in it were given, to calculate the velocity of the draught: thus, if the height of the chimney were 50 ft., and the air contained in it 10 degrees hotter than the external air, the expansion would be one-fiftieth, and the pressure of the whole column being diminished one-fiftieth, the difference would be equivalent to a column of 1 foot in height, and such a column would represent the pressure causing the draught, which might, therefore, be expected to have a velocity of 6 feet in a second." Perhaps I should remark, in parenthesis, that the theoretical velocity is the square root of twice the product of the acceleration due to gravity and the height of the motive column, $\sqrt{2gh}$, and in the present example amounts to 8 ft. per second, not 6 ft. per second, as stated by Young. This computation ignores the effect of friction or other resistance, which, of course, reduces the velocity considerably. "If the room were perfectly closed, the air contained in it would, by degrees, become so much lighter than the external air, as would be equivalent to 1 foot of the height of the column causing the pressure, and the current would then stop ; if fresh air were gradually admitted by a small orifice, the current would again go on, but the air in the room would always remain somewhat rarer than the external atmosphere, unless a fresh supply were admitted through ample openings.

---

[1] "A Course of Lectures in Natural Philosophy and the Mechanical Arts." London 1807.

" The object of a chimney is not so much to ventilate the room, as to provide a sufficiently rapid supply of air for maintaining the process of combustion, and to carry off the products of that process : hence, it is desirable to allow as little air as possible to enter the chimney without passing through the fire ; and this is the best general method of avoiding smoky chimneys."

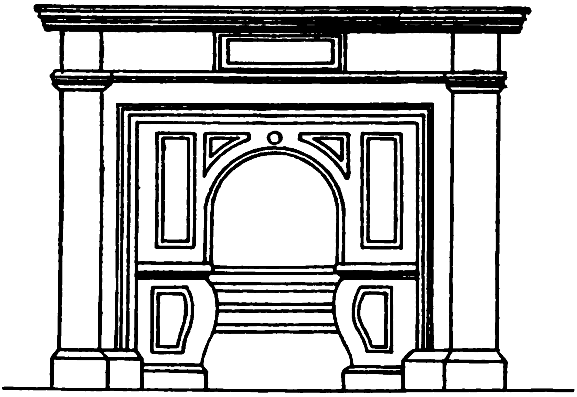


FIG. 1. BATH GRATE (LATE EIGHTEENTH CENTURY). (FROM " OUR DOMESTIC FIREPLACES," 1870.)

The Bath grate, which had a considerable vogue in Young's day, was designed so that the opening above the fire was considerably reduced and it achieved some reputation as affording the only cure for an incorrigible chimney. The grate was very wasteful in fuel, however, and one writer remarked that " it must be admitted that in numerous apparently hopeless cases the Bath fire-place did its business effectually ; and where the flue was of a good height it did wonders : the draught carried everything triumphantly before it ; not only the smoke but all the air in the room whisked up the chimney with the velocity of a hurricane, followed by all the comfort at a speed as rapid."

It has been suggested that smoky chimneys fall naturally into two groups, those which are troublesome at all times and those whose performance varies with the wind. This is quite a legitimate division and I shall have something to say about the specific action of the wind. I feel, however, that smoky chimneys ought rather to be divided into those which smoke only when the fire is newly lit and those which are not so particular. Twenty years ago, at the Annual General Meeting, Mr. Edgar Herring, then Vice-President, read a paper before the Institution on the subject, " What Happens

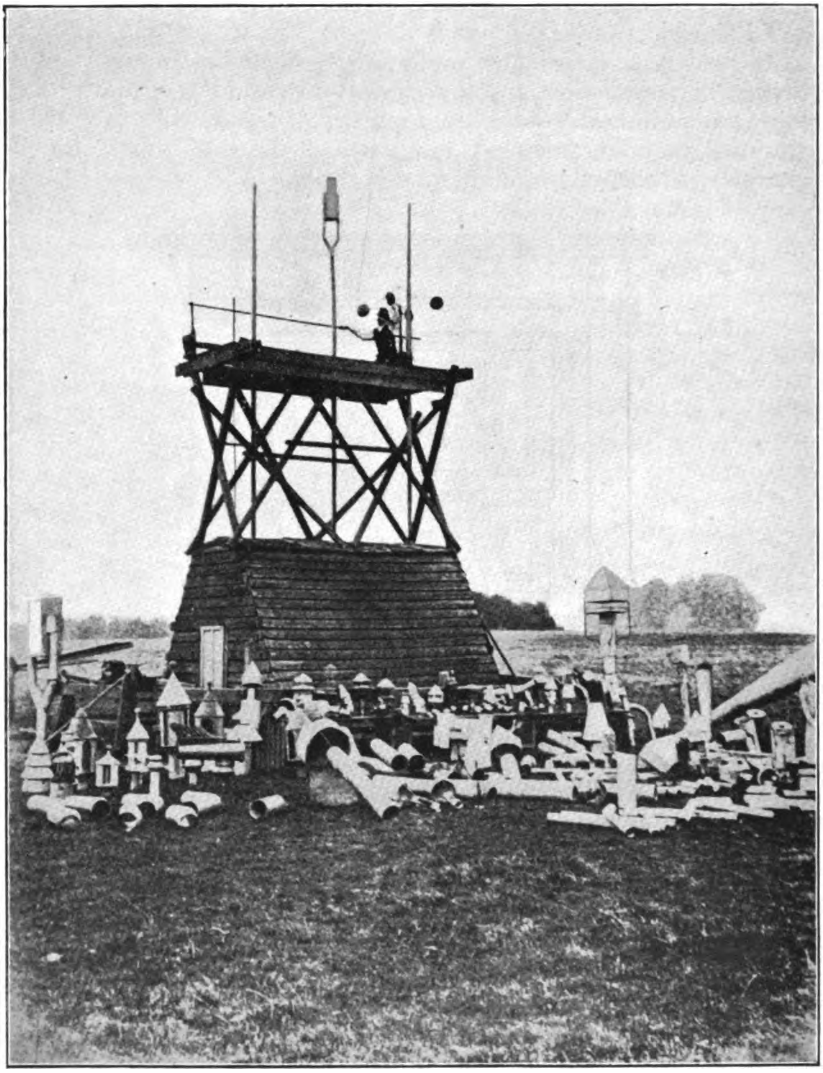


FIG. 2. EXPERIMENTAL HUT AT KEW, WITH THE COWLS AND TERMINALS TESTED (FROM "JOURNAL OF SANITARY INSTITUTE," 1901).

when the Fire is Lighted ? "[2] The smoky chimney seems, however, to have been included among the number of points which he would have liked to have dealt with but which he left for a future occasion. I was reminded of Mr. Herring's paper by an item in the newspaper[3] pointing out that at Baltimore, in America, an hotel had been built and completed and boilers installed and that it was only when the fires were lit that it was found that the building did not have a smoke-stack at all !

It is well known that when a fire is burning under a flue, the hot gases rise and induce ventilation. With an unheated flue, however, no energy is supplied and the flue merely affords an aperture which does not differ essentially from a roof or wall ventilator—though the aperture may be differently affected by wind.

The effect of wind blowing across the terminal of an unheated flue formed the subject of an extensive series of experiments undertaken by a committee of the Sanitary Institute appointed in 1878 to test ventilating exhaust cowls.[4] It was the intention of the committee to assign a number to indicate the efficiency of the cowl or terminal under consideration but, as Mr. W. N. Shaw, now Sir Napier Shaw, has pointed out, the effect of a terminal cannot really be dealt with by a single factor : the efficiency ought to be estimated with regard to the circumstances in which it is to be used. If it is to draw air from a nearly closed space, its resistance to flow may be disregarded, and its efficiency estimated according to its capacity for producing aeromotive force ; but in most cases of ventilation the resistance must also be taken into account. The greater number of terminals examined, however, were of such a shape that they did not appreciably add to the resistance of the circuit and the " efficiency " found by the committee corresponds to the change produced in aeromotive power.

The results show that by modifying the terminal of a straight pipe it is possible to increase the aeromotive power by as much as 50 per cent. One method of effecting this is by opening out the end of the pipe like a trumpet. The committee determined not only efficiencies, but also the possibility of down-draught due to wind blowing at an angle to the terminal ; and designed terminals which were free from down-draught. A proper terminal is important whenever a chimney is commanded or overlooked by trees, by buildings or by other obstacles to the wind ; its virtue is then almost magical and, in consequence, particular terminals achieve a reputation as a panacea for smoky chimneys.

That the terminals which so frequently adorn our buildings seldom have any æsthetic appeal is greatly to be deplored and there

---

[2] Proc. Inst. H. & V. Eng., 1914, Vol. 15, p. 21.

[3] *Sunday Express*, March 4th, 1934.

[4] *Jour. of the Sanitary Institute*, 1901, Vol. 22, pp. 201-452.

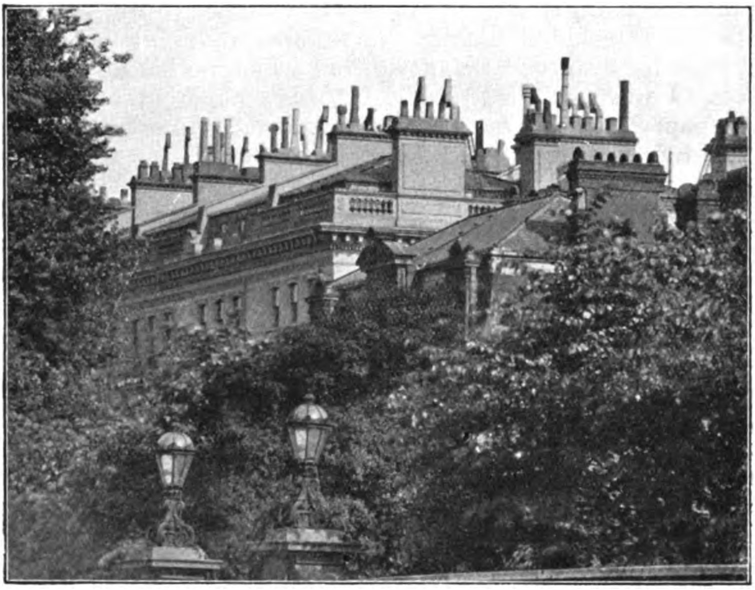


FIG. 3. LONDON CHIMNEYS.

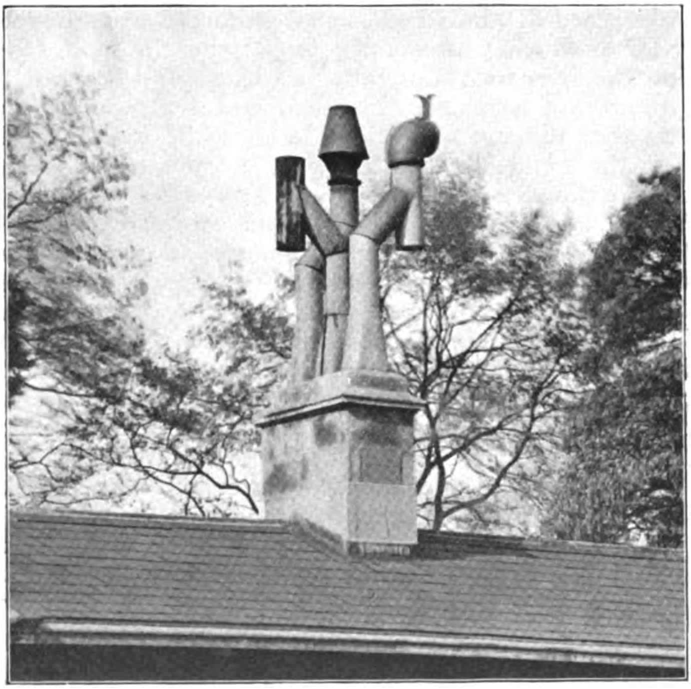


FIG. 4. LONDON TERMINALS.

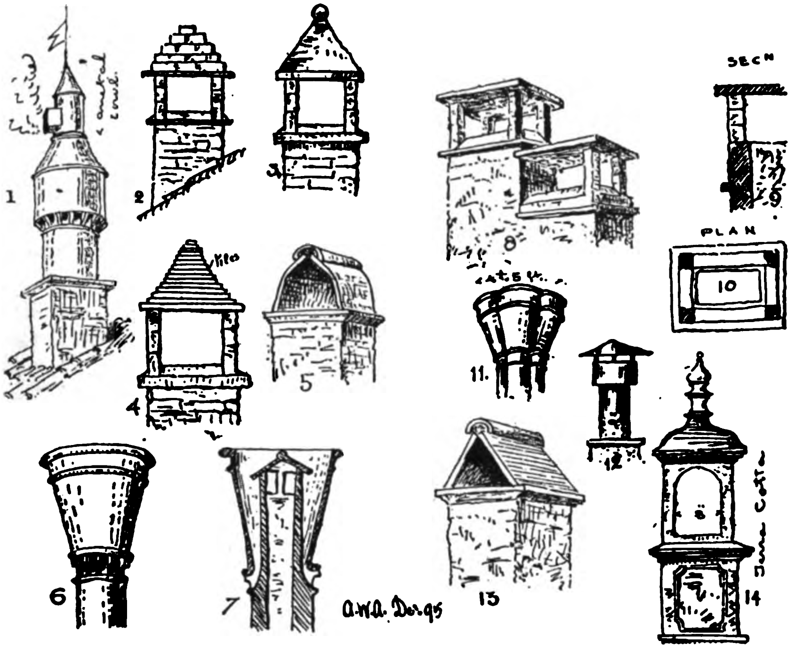


FIG 5.. VENETIAN TERMINALS (FROM "JOURNAL OF SANITARY INSTITUTE," 1901).

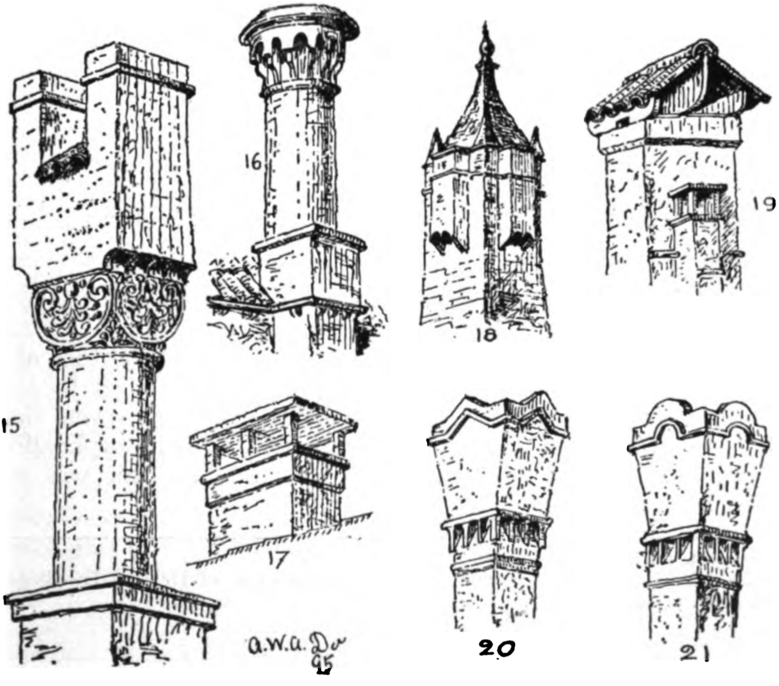


FIG. 6. VENETIAN CHIMNEYS (FROM "JOURNAL OF SANITARY INSTITUTE," 1901).

is a marked contrast between the terminals of South Kensington, for example, and some of those to be found in Venice.

A word of caution is necessary here. Although it is possible to devise a terminal which will prevent down-draught from wind blowing at the top of a pipe, the prevention of down-draught due to suction at the lower end of the pipe is a much more serious matter. If, for example, there are two fire-places in one room, and the air-inlets are inadequate, it is a case of " pull Devil, pull Baker ! " Wind blowing through a restricted opening, moreover, such as a gap between two buildings, creates a zone of low pressure and if the air-inlets to a room are situated in such a zone the chimney will be affected. It may be observed, also, that the pressure in the lee of a building is lower than that on the windward side.

An ingenious attempt to obviate down-draught due to suction was made in the design of " balanced flues " for gas-radiators. The inlet and outlet were brought out in juxtaposition in the expectation that they would be equally affected by the vagaries of the wind. This expectation was largely fulfilled but, as Mr. C. A. Masterman mentioned in the discussion of his paper on " Combustion, Wind and Flue Equipment,"[5] the system was not a complete success because, in a gust, wind struck one terminal before the other and also because the pressure-wave reached the burner quicker by one route than by the other. It must be pointed out, however, that the balanced flue is older than the gas-radiator and in its application to ventilated gas-lights the design was such that the flue was not affected by wind.[6]

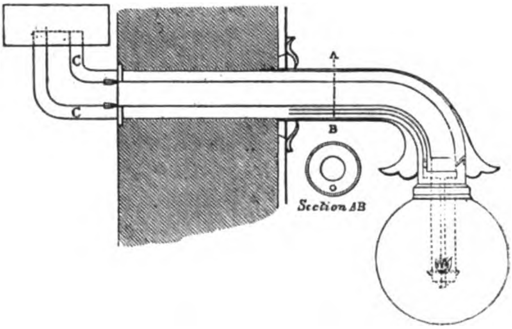


FIG. 7. VENTILATED GASLIGHT (FROM GALTON'S " HEALTHY DWELLINGS ").

---

[5] Proc. Inst. H. & V. Eng., 1930. Vol. 28, p. 326.

[6] *cf.* Douglas Galton, " Observations on the Construction of Healthy Dwellings," Oxford, 1880, p. 173.

There are other ways in which wind can affect flue draught. It is not generally known, for example, that the wind can blow right through the walls of some chimney-stacks. When, moreover, a chimney is on an external wall, particularly a north or an east wall, the cooling power of the wind acting upon one side of the flue may cause a serious down-draught. The converse effect is caused by the sun's heat on a chimney exposed on a south wall. This induces a favourable draught and to enhance this effect the expedient of blackening the outside of the chimney stack has been suggested.

If a chimney smokes only when the fire is newly lit, the reason may be a structural one, and I must refer here to the function of the smoke-shelf. The smoke-shelf is now a traditional part of a fire-place. From time to time people who do not understand its purpose decide that a smoke-shelf is not wanted, and attempt to do without it. The result is that, when the fire is lit and the warm gases rise up in the cold chimney, the gases, becoming cooled, descend in a counter-current which escapes into the room. When a smoke-shelf is provided the counter-current becomes a mere eddy and is diverted up the chimney again. The velocity of this counter-current is reduced in the " smoke-chamber " above the smoke-shelf and it cannot compete against the flow of warm gases entering the throat of the chimney. The smaller the area of the throat the higher will be the velocity of the entering gases, but the area of the throat should not be less than that of the flue or it will unnecessarily increase the resistance. It is an advantage, moreover, if the lower part of the flue rises vertically and is not offset just above the throat.

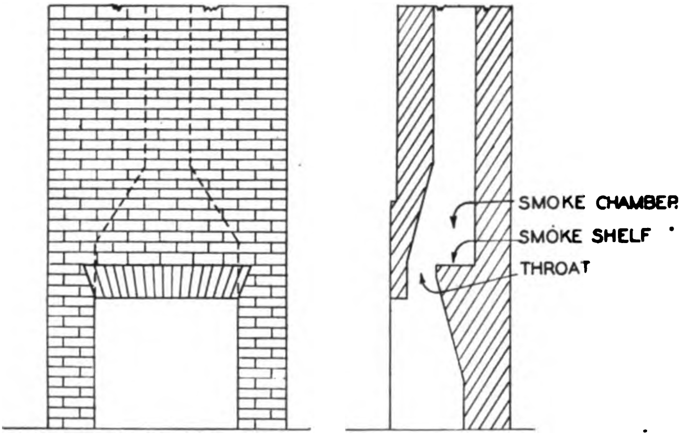


Fig. 8. Smoke-shelf and Smoke-chamber.

It may be mentioned here that when a fire is required in a grate which has not been used for some time, it may be expedient to light the fire either in the early morning, or else late in the evening. The temperature then is likely to be higher within doors than it is outside, and the chimney will draw better.

It is difficult for us to realise the inconveniences of the large open fire-places of the good old days and I was much impressed by the description in Dr. Benjamin Franklin's paper of 1745 describing his new-invented Pennsylvanian fire-place. Of large open fire-places, he says, " Their inconveniencies are, that they almost always smoke, if the door be not left open ; that they require a large funnel, and a large funnel carries off a great quantity of air, which occasions what is called a strong draught to the chimney, without which strong draught the smoke would come out of some part or other of so large an opening, so that the door can seldom be shut ; and the cold air so nips the backs and heels of those that sit before the fire, that they have no comfort till either screens or settles are provided (at a considerable expence) to keep it off, which both cumber the room, and darken the fireside. A moderate quantity of wood on the fire, in so large a hearth, seems but little ; and, in so strong and cold a draught, warms but little ; so that people are continually laying on more. In short, it is next to impossible to warm a room with such a fire-place : and I suppose our ancestors never thought of warming rooms to sit in ; all they purposed was, to have a place to make a fire in, by which they might warm themselves when cold.

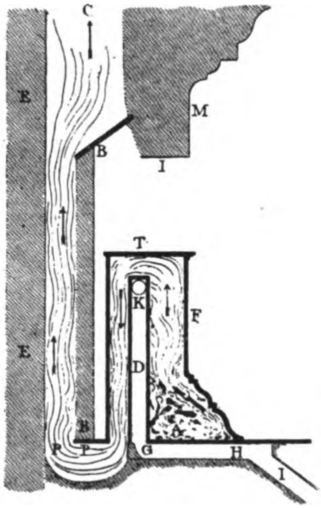


FIG. 9. PENNSYLVANIAN FIREPLACE (FROM FRANKLIN'S " COLLECTED WORKS ON PHILOSOPHY, POLITICS AND MORALS ").

"Most of these old-fashioned chimneys in towns and cities, have been, of late years, reduced . . . by building jambs within them, narrowing the hearth, and making a low arch or breast. It is strange, methinks that though chimneys have been so long in use, their construction should be so little understood till lately, that no workman pretended to make one which should always carry off all smoke, but a chimney-cloth was looked upon as an essential to a chimney. This improvement, however, by small openings and low breasts, has been made in our own days; and success in the first experiments has brought it into general use in cities, so that almost all new chimneys are now made of that sort, and much fewer bricks will make a stack of chimneys now than formerly."

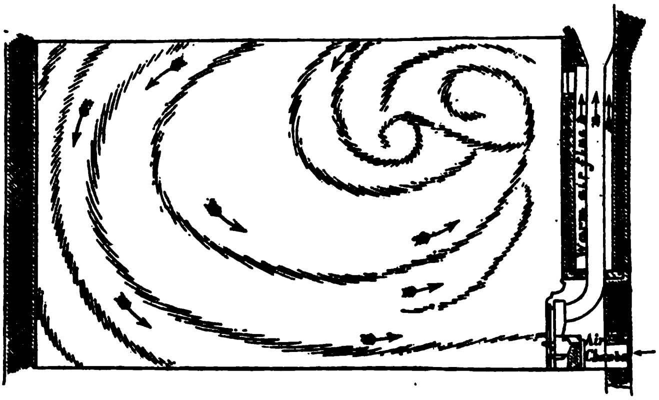
Franklin had more to say on this subject in a letter to Dr. Ingenhausz:[7] "Architects in general have no other ideas of proportion in the opening of a chimney, than what relate to symmetry and beauty, respecting the dimensions of the room: while its true proportion, respecting its function and utility, depends on quite other principles; and they might as properly proportion the step in a staircase to the height of the storey, instead of the natural elevation of men's legs in mounting. . . . If in large and elegant rooms custom or fancy should require the appearance of a large chimney, it may be formed of extensive marginal decorations, in marble, etc. In time, perhaps, that which is fittest in the nature of things may be come to be thought handsomest. But at present, when men and women in different countries show themselves dissatisfied with the forms God has given to their heads, waists and feet, and pretend to shape them more perfectly, it is hardly to be expected that they will be content always with the best form of a chimney. And there are some, I know, so bigoted to the fancy of a large noble opening, that rather than change it, they would submit to have damaged furniture, sore eyes, and skin almost smoked to bacon."

That we have not progressed much in the ventilation of houses since Franklin's day can only be ascribed to ignorance and to apathy. It is not that the principles of good ventilation have not been formulated or that there is anything mysterious in their application. Fifty years ago, a valiant attempt was made to inculcate sound ideas by Captain Douglas Galton, F.R.S., and in the preface to his "Observations on the Construction of Healthy Dwellings," he remarks that "The researches of the physiologist and of the medical man into the laws which govern the prevalence of diseases have enabled them by the gradual accumulation of information, to lay down the principles upon which the construction of houses should rest. It is the duty of the architect, the builder, the engineer, and the surveyor to apply these principles, and their correct application is as essential to the efficient construction of a dwelling as is the quality or strength of the materials which are used to build the dwelling."

---

[7] Franklin. "Observation on the Causes and Cure of Smoky Chimneys," 1787.

In spite of this how seldom do we find a house in which satisfactory provision has been made for ventilation. Franklin's remark about cold air nipping the backs and heels of those that sit before the fire is generally applicable to-day. Galton's own idea was that, although the windows, when they can be kept open, are the best means for the renewal of the air in a room, every room should nevertheless have special inlets and outlets for air, arranged so as to be independent of the windows.



Section of a room with a ventilating grate and warm-air flue, showing action of fire in producing circulation of air.

FIG. 10. VENTILATING FIREPLACE (FROM GALTON'S "HEALTHY DWELLINGS").

It does not cost much to instal inlets for air when a house is built and, if the incoming air is warmed by conduction from the chimney-flue, very substantial economy is effected. With his Pennsylvanian fire-place Franklin reckoned to save no less than five-sixths of the fuel required to heat a room.

In securing this result Franklin may have reduced the ventilation to a minimum. It is interesting, therefore, to record that, about 1865, General Morin, who considered that the whole of the air should be renewed five times in the hour, experimented with Galton ventilating fire-places and found that to produce the same degree of warmth in a room the grate required little more than one-third of the quantity of coal required by an ordinary grate.[8] The ventilation was effected by passing through the room in one hour a volume of air, equal to five times the cubic contents of the room and we are told not only that an equable temperature was maintained during the experiment, but also that there was no perceptible draught, and although the doors fitted badly, scarcely any air was drawn in through the crevices.

---

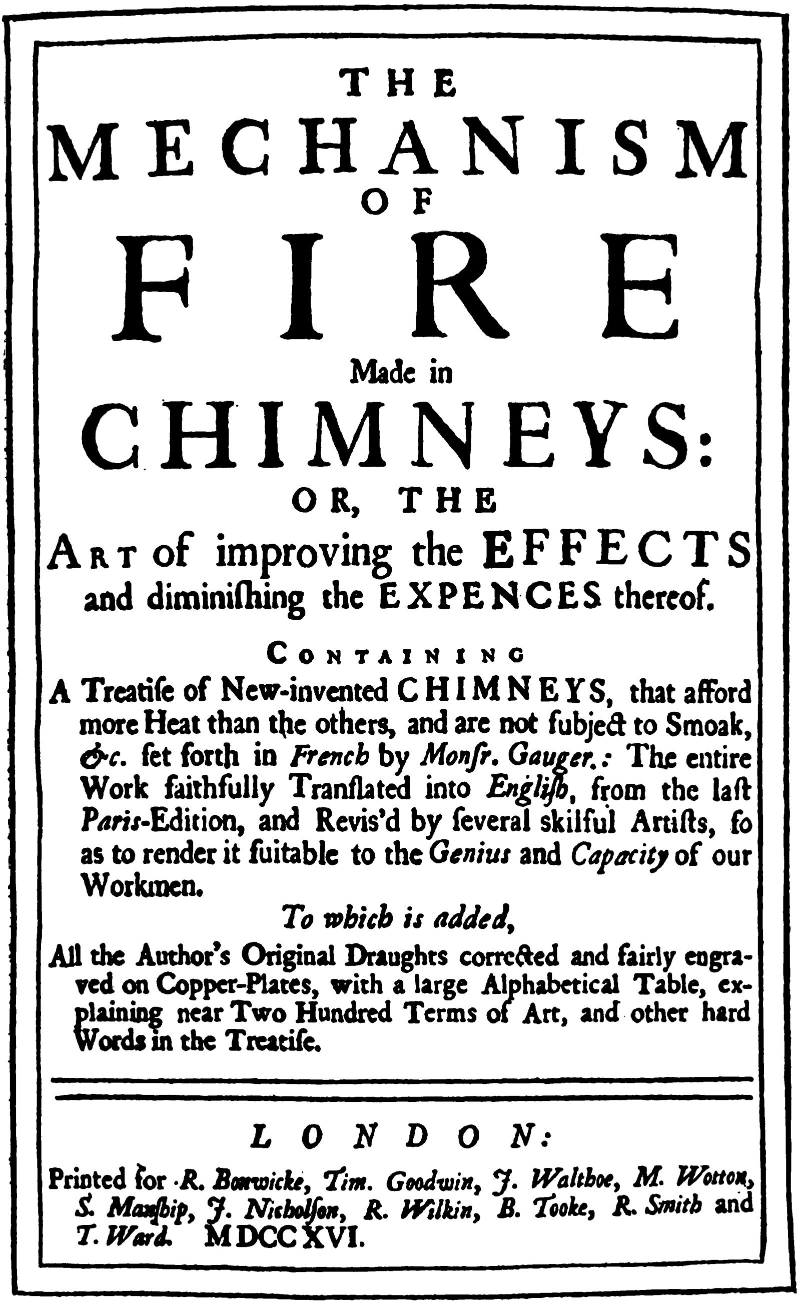
[8] Galton. "Observation on the Construction of Healthy Dwellings," p. 135.

I have suggested that with his Pennsylvanian fire-place Franklin may perhaps have reduced the ventilation to the minimum. He was careful, however, about the purity of the air he breathed. "In rooms where much smoking of tobacco is used," he wrote, "it is also convenient to have a small hole, about five or six inches square, cut near the ceiling through into the funnel: this hole must have a shutter, by which it may be closed or opened at pleasure. When open, there will be a strong draught of air through it into the chimney, which will presently carry off a cloud of smoke, and keep the room clear: if the room be too hot likewise, it will carry off as much of the warm air as you please, and then you may stop it entirely, or in part, as you think fit. By this means it is, that the tobacco smoke does not descend among the heads of the company near the fire, as it must do before it can get into common chimneys."

A somewhat similar method of ventilation achieved a certain popularity in Victorian times, and in my grandfather's house there was an arrangement which I think must have been an Arnott's chimney valve. There was a ventilator into the chimney-shaft near the ceiling, and it was fitted with a talc flap-valve to prevent down-draughts of smoke from coming into the room. I can well remember the flapping of the valve on a gusty day.

I have referred to Franklin's Pennsylvanian fire-place and to Galton's ventilating fire-place. These were preceded by the fire-places of Monsieur Gauger, who in 1713, published "La Mecanique du Feu," which contains a treatise on the subject and describes a number of different constructions. This book was translated into English and published in 1716 under the title "The Mechanism of Fire made in Chimneys." Monsieur Gauger made a very notable contribution to the art of heating and ventilating and has been reputed to be the true and first inventor of the ventilating fire-place. But *vixere fortes ante Agamemnona* and Gauger himself refers us to Monsieur Savot's description of a cavity made under the hearth and behind the back of the chimney of the library of the Louvre at Paris, to point out that the air that passes therein takes but a short course and will not sensibly grow warm.

He finds his own arrangements much more satisfactory and, in Part II, Book I, tells us that "This Air, which comes thus continually from without into a Chamber, heating it more and more, may do it even to a degree that would be troublesome. Now it is an easy matter to prevent such an Inconvenience, in case it be perceiv'd, by stopping the Aperture R thro' which the hot Air comes in; so that without diminishing the Fire, the Heat would



THE
MECHANISM
OF
FIRE
Made in
CHIMNEYS:
OR, THE
ART of improving the EFFECTS
and diminiſhing the EXPENCES thereof.

CONTAINING
A Treatiſe of New-invented CHIMNEYS, that afford more Heat than the others, and are not ſubject to Smoak, *&c.* ſet forth in *French* by *Monſr. Gauger.:* The entire Work faithfully Tranſlated into *Engliſh*, from the laſt *Paris*-Edition, and Revis'd by ſeveral skilful Artiſts, ſo as to render it ſuitable to the *Genius* and *Capacity* of our Workmen.

To which is added,
All the Author's Original Draughts corrected and fairly engraved on Copper-Plates, with a large Alphabetical Table, explaining near Two Hundred Terms of Art, and other hard Words in the Treatiſe.

LONDON:
Printed for *R. Bonwicke*, *Tim. Goodwin*, *J. Walthoe*, *M. Wotton*, *S. Manſhip*, *J. Nicholſon*, *R. Wilkin*, *B. Tooke*, *R. Smith* and *T. Ward*. MDCCXVI.

Fig. 11. Title Page of "The Mechanism of Fire."

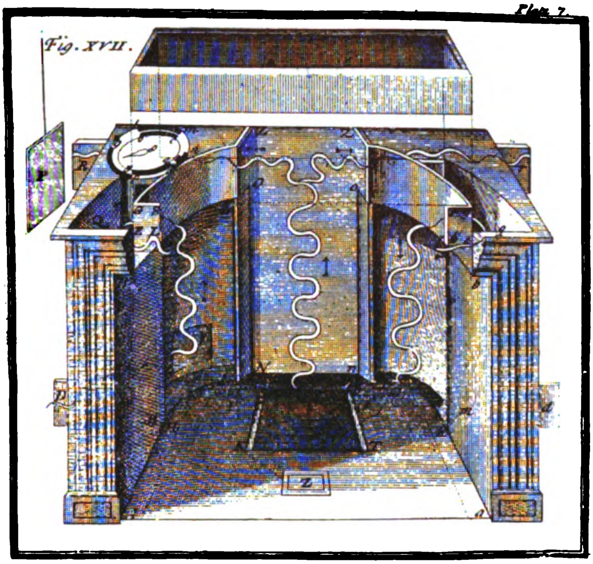


FIG. 12. VENTILATING FIREPLACE (FROM "THE MECHANISM OF FIRE").

abate or cease from augmenting : But we should no longer receive fresh Air, which is the greatest Advantage of this Disposition of a Chimney, as will appear in the Sequel.

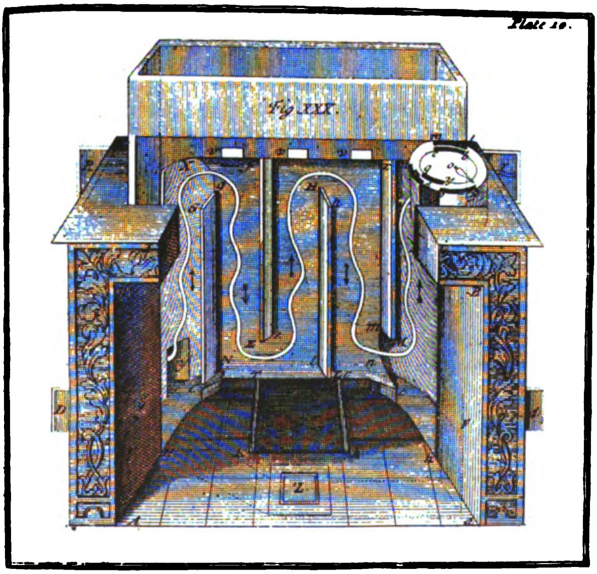


FIG. 13. VENTILATING FIREPLACE (FROM "THE MECHANISM OF FIRE").

" It is therefore more expedient to leave a Communication with the cool Air that comes directly from without, near the Place R where it issues forth hot ; to the end that we may be always able to let in Exteriour Air, sometimes warm, sometimes cool, and when it is thought fit, temperate, or mixt with hot and cold, to any Degree whatsoever, at Pleasure ; by opening either or only such part as shall be judg'd proper of the two Conduits, thro' which the cold and hot Air may pass, and so augment and diminish the heat of the Room without encreasing or lessening the Fire. In the third Book, we shall lay down the means of doing it after the most convenient manner."

Gauger was an observant man and full of commonsense. In discussing the warmth of a room, he considered that too much attention should not be paid to the indications of a thermometer. " That those Persons are very much mistaken," he remarked, " who with an intention continually to have the same degree of Heat, would keep in their Chamber, such a one as makes the Liquor of their Thermometer rise to the same height : For if that degree of Heat were really always the same, and their Thermometer were not also as uncertain as we have elsewhere observed that it is, they would almost ever feel a different Heat, accordingly as they themselves are more or less hot. . . .

" We are therefore to judge by our Senses of the Degrees of Heat and Cold that are agreeable to us, and not by what exteriour Objects more especially inanimate ones may represent to us ; and notwithstanding that the Thermometer shews us ever so fairly, that the Air of our Chamber is very hot ; yet if we feel it cold, it is absolutely necessary to encrease its Heat."

I expect that you will be thinking that this little homily might appropriately have been addressed to architects. So it might ! And I fully realise that up to now the heating and ventilating engineer has not had much professional use for the domestic fireplace—except, perhaps, to supplement central heating. The broad fact remains, however, that heating and ventilating are inextricably linked and doubtless the time will come when every room will have special arrangements for the admission and extraction of air. In cold climates, the warmed air should be admitted independently of the windows, which, after all, are so placed in a room as to meet the requirements of light, and do not therefore necessarily occupy the most advantageous position for the admission of air.

The heating and ventilation of ordinary dwellings is undoubtedly a field which has not yet been properly cultivated. It may be capable of yielding a rich harvest. In conclusion, a short extract from Gauger's preface.

" To be able to kindle a Fire speedily, and make it (if you please) flame continually, whatever Wood is burning, without the use of

Bellows; to give Heat to a spacious Room, and even to another adjoining, with a little Fire; to warm one's self at the same time on all sides, be the weather ever so cold, without scorching; to breath a pure Air always fresh, and to such a degree of Warmth as is thought fit, to be never annoy'd with Smoak in one's Apartment, nor have any Moisture therein; to quench by one's self, and in an Instant, any Fire that may catch in the Tunnel of a Chimney: All these are but a few of the Effects and Properties of these wonderful Machines, notwithstanding their apparent Simplicity and Plainness. What is there then, I pray, more commodious, more usefull, or even more necessary?"

DISCUSSION.

The President said that Mr. Dufton's paper had been an extremely interesting one. He was rather sorry that not more ladies were present, because he thought that some of the matters which Mr. Dufton had brought forward would have been of special interest to them. The paper raised in his mind a large number of questions which might be explored further, and it would be interesting to have the views of some of those present on the problems which the paper had opened out.

Mr. Walter T. Dunn, M.I.Mech.E. (Hastings), after expressing his appreciation of the invitation given to him as a visitor to be present, said that when the author of the paper began he could not help wondering whether he had really very fully considered the effect of offering such a paper to that distinguished Institution. Mr. Dufton had stated that in his own house he used anthracite, coke, and gas. He had proceeded to give a most interesting description of various historic arrangements of domestic heating, and no doubt members who had a special interest in the subject would appreciate the value of the references to what had been done in the past. But he hoped that in considering the whole subject members would not confine themselves, with all due respect to the author, to what had been stated in the paper. He contended that if the members would consider what they had available in connection with heating and ventilation already they would not require to study the question of smoky chimneys at all. They all knew very well, as the author had pointed out, and had illustrated by some telling photographs, that in London and other large towns the tops of the houses were hideous spectacles on account of the varied ugliness of the cowls and terminals. That, of course, was obvious. He thought that the whole matter would soon become quite out of date. In fact, he was rather surprised that the municipal authorities of certain towns did not exercise the power they possessed to prevent such monstrosities being put up at all. Why should those who went about the streets of towns have their eyes continually offended by these spectacles on the roofs? The time was rapidly coming when, with the assistance of experts like those present, that would all be eliminated.

If he might go a little further in connection with the coal-grate, he felt that the day of the coal-grate was also gone. In the work of the heating engineer he need not consider the necessity of making provision for coal-grates. In the paper it was mentioned that chimney stacks did not require, by the new methods of design, so many bricks. That had been brought about through the use of gas-fires. The recess on each side of the fire-place used to be a matter of great pride to householders. It was a convenient place in which to put the sideboard or other furniture. But nowadays it was possible to increase the area of the room and diminish the space taken by the chimney, owing to the fact that gas-fires instead of coal-fires might be used. At Bournemouth, when the British Commercial Coal Gas Association had its meeting, the chairman of that body received a deputation of chimney sweeps. These people were concerned by the evident possibility that within a short time their trade would become extinct. Therefore, they met the chairman of that Association and implored him to consider the making of arrangements for the entrance of their sons into the gas industry because there would be no possibility of their employment in their fathers' calling. That might sound rather comical, but it showed the direction in which events were tending, and he begged, with all deference, to suggest that the members of the Institution should consider the application of modern methods of heating of which the gas-fire was an outstanding example, and dismiss from their minds the necessity for the further existence of the coal-grate. The coal-grate had its advocates on the æsthetic side. It had given the artist the opportunity for introducing some beautiful mantelpieces and so forth, but it was open to question whether they should submit to all the manifest inconveniences of the coal-fire on account of considerations such as these. In enlightened times such as the present it was surely unnecessary. In Hastings—his own town—the development of gas-fires had been most remarkable. When he came there as a resident he found installed in his house coal-fires, and at once saw the inconvenience of them and the dirt they caused, and so turned over to gas. In conclusion he desired once again to thank the Institution for their kindness in inviting him to the meeting. He was himself an engineer and took a great interest in these problems.

Mr. W. E. Fretwell thanked Mr. Dufton for his interesting paper. It was exactly the type of paper desired for a Summer Meeting, and one which members must have thoroughly enjoyed. As for the last speaker, he was rather wondering whether there was any electricity department in Hastings. If one wanted to do away with chimneys the matter was very simple—to use electricity.

Mr. Dunn: What about the absence of ventilation?

Mr. Fretwell said that they were also ventilating engineers and could assist in that respect. Mr. Dunn had also referred to the ugliness of the chimney pot and with his suggestion that the authorities should take steps to prevent these hideous things he thoroughly agreed. He had been interested in the author's remark about the purpose of the smoke-shelf in the construction of the chimney. He rather thought that, in addition to the use for it suggested by Mr. Dufton, it was also introduced to prevent rain splashing down the chimney into the room ; at any rate it did fulfil that function, the rain falling down the chimney splashing onto the shelf, and not entering the room. When he built his own house he put in central heating, but he also preserved some open fire-places, and there was no doubt, central heating notwithstanding, as to the part of the room where he and his family liked to sit on a winter's night.

The author had referred to a paper read before the Institution twenty years ago by Mr. Edgar Herring. He had referred to an hotel in America which had been built and completed, and only when the fires were lighted was it discovered that the building did not have a smoke-stack at all! He recently returned from a trip abroad and found on his desk a report of what happened in a recent institution. When the fire was lighted the chimney-stack collapsed.

Mr. W. W. Nobbs said that a previous speaker had suggested that the subject of the paper was hardly suitable for this Institution, but he thought he was to be forgiven for that opinion as he was a visitor. At their Summer Meetings they had ladies and other attractions and liked a little lighter fare, and he was sure that all the members had thoroughly enjoyed the paper. Mr. Dunn had also suggested that municipal authorities might do away with chimney-pots. Much as he hated to draw distinctions between American practice, he felt bound to draw attention to the example in the slide illustrating the Baltimore Hotel, showing the extent to which America had gone ahead of them.

Mr. W. Mumford Bailey said that he desired also to thank the author for his paper. He succumbed to certain influences which were brought to bear on him and built one fire-place in his house and it smoked. He felt that he had now two alternatives, either to reproduce the efforts of the Office of Works and put on the top of his house a cowl, or to rely on his skill as a heating engineer and enforce his opinion and do away with the fire-place entirely. He thought that as an engineer he would choose the latter course. He was rather hoping that Mr. Dufton in dealing with heating and ventilating problems would go on to consider what in his opinion was their greatest problem, namely, the weight of the dead hand of tradition upon them. All the way through their industry they seemed to be under the domination of what people used to do in old times. They still carried on very much as the ancients did. They had been told—and much ingenuity had been applied in proving—that the Romans were the finest heating engineers who ever lived, and they had gone on using their methods. He also had in mind at least one hotel, the amenities of which so far as heating was concerned, he imagined, might have been installed just after the famous battle of Hastings which had been mentioned that morning. Heating engineers were still labouring under this incubus. While the paper was being read he could not help wondering whether some of the spectres of the past were not rattling their chains. About 90 per cent. of the fire-places in this country never had any coal in them, nor did the chimneys emit any smoke. That was something which should encourage heating and ventilating engineers to arrange conditions for warming and ventilating houses which would not waste so much money as was entailed by provision for the open-fire. In his view the open-fire should be discouraged.

Mr. S. Adams thanked Mr. Dufton for his very interesting paper. Mr. Dufton had dealt with different causes of down-draught, both from winds and from induced draught. He had also told them what had been done in former times with regard to the closely linked association of heating and ventilation. To himself it suggested the question as to how far they were advancing in these modern times, whether, with flueless rooms, they were attending to heating, but not enough to ventilation. It was very essential to attend to both. As the author himself had said, heating and ventilation were inextricably linked. He thought that the Institution might well consider whether in modern buildings ventilation was not being sacrificed for the sake of cheapness. The provision of adequate ventilation in modern constructions was a matter which the Institution might well take up. It often happened in these large buildings that the provision of flues was such that the smell of cooking was carried through from kitchens to drawing-rooms, and in a block of flats where the only chimney-flue was the boiler-flue everything was drawn from flat to flat right through the building to the boiler-flue. The atmosphere was very uncomfortable in some modern flats unless the windows were opened, and if windows were opened there was perhaps an undue draught. The picture shown had illustrated how their predecessors had attempted to obtain relief in these matters, and the Institution had an opportunity to make further progress.

Mr. G. L. Copping said that Mr. Dufton had opened his very interesting paper by explaining the difficulty he had in selecting a subject. He would suggest that possibly the Publicity Committee might help matters by giving regular indications in the *Journal* as to the subjects on which papers were desired. This they could easily do by collating the various lines of research going on in different quarters.

As a fan engineer, the speaker had been rather impressed at the pitiable state in which the domestic dweller seemed to be placed. It seemed to him that a careful study of domestic requirements, especially in view of the present vogue for short-wave infra-red heating might be very useful. At the present time it seemed to him that the best thing for a man in a dwelling-house was to forget all about chimneys and buy a small fan and ventilate his dwelling positively and comfortably. But connected with the provision of the fan there would necessarily be the question of warming the rooms. The gas industry told them to put in a gas-fire, and claimed great things for a short-ray infra-red fire. The electricity people said that with ventilation the electric fire was best. Although a fan man he found that the best way so far of heating his own house was to retain the good old-fashioned chimney and to burn in the grates coalite or some smokeless fuel.

Mr. L. J. Fowler expressed his agreement with the last speaker regarding the virtues of smokeless fuel. To the Englishman who, for the most part, lived in a small house it would be very difficult to justify central heating economically. When it came to large blocks of flats such as were fashionable in America, Germany and Austria, central heating might be desirable. There were many forms of smokeless fuel available, and these seemed to him to offer the best solution.

Mr. Alcwyn A. Jones thanked Mr. Dufton for his very interesting paper, which had taken them back to early history. Even in historical papers, however, a certain amount of variation of opinion was forthcoming. He had mentioned Monsieur Gauger in relation to Franklin's Pennsylvanian fire-place. This reference was rather interesting from two historical points of view. First of all Monsieur Gauger was at one time supposed to be the assumed name of Cardinal de Polinac, but this theory was exploded by Charles Tomlinson in his " Rudimentary Treatise on Warming and Ventilation," published 1864. The second point was that in a book published in 1825, written by " An Engineer," supposed to be R. S. Mickleham, a civil engineer who supplied the design for the plates, it was definitely stated that Gauger's treatise " contained many valuable suggestions. Dr. Franklin borrowed the construction of what he denominated his Pennsylvania stove, both in compliment to his newly-adopted country and more effectually to conceal the origin of its invention." So it appeared that Gauger should be credited with the stove rather than Franklin. Gauger's book under the title of " The Mechanism of Fire made in Chimneys ;

Or the Art of Improving the Effects and Diminishing the Expenses Thereof," was translated by Dr. Desaguliers and published in London in 1716.

Mr. Dufton had referred to what he thought must have been Arnott's chimney valve in his grandfather's house, but the speaker thought that the Arnott valve was not quite the same as that described by Mr. Dufton. It was composed of a metal box, and had a single metal flap balanced by a ball, so that when the air passed from the room to the chimney it opened automatically, and when reverse pressure was encountered the flap was closed. The device described by Mr. Dufton was more likely that of Dr. Boyle, who introduced the mica flap in a ventilator. Both these types ceased to be popular owing to the flapping noise of which Mr. Dufton had spoken, also because sometimes soot was blown into the room, owing to defective fitting.

The paper had made them think of the future. There was a tendency at the present day in one or two countries to introduce air-conditioning appliances or apparatus for the home, and he thought that was a line on which heating engineers would be moving shortly in this country.

Mr. Edgar Herring said that the spirit of prophecy seemed to have descended upon them that morning. First of all he desired to congratulate Mr. Dufton upon introducing a paper in a lighter vein than the papers with which he had previously favoured them. He also wished to contribute to the cheery spirit in which the paper had been received by relating a little incident which took place some years ago in connection with a house in which he was living. The dining-room chimney, when he went into the house, appeared to be all right, but a few months after the winter season opened the dining-room flue began to smoke most abominably. He tried every means in his power to ascertain the cause of it. He even went to the expedient of putting in a gas-fire as recommended by Mr. Dunn, but he was then troubled, not with smoke, for it was certainly a smokeless fuel, but by gas fumes pervading the whole room. By sheer good fortune he ultimately found out the cause of this trouble. Happening one day to walk on the other side of the road, he noticed that his next-door neighbour (it was a semi-detached house) had erected a cowl of the ordinary type, with a straight-up discharge, with two arms projecting from the sides. He supposed that all present had seen these cowls in great profusion round about London. Unfortunately for him, his neighbour had had it fixed in such a way that an arm on one side came directly over the top of his flue. The result was quite obvious. When the wind came in contact with the upper lip of this arm it came down the flue. He solved the problem by employing a builder to turn the cowl round so that the arm projected over his neighbour's own flue.

There was one little point in connection with a slide thrown on the screen showing the smoke-shelf. He understood Mr. Dufton to recommend that the flue should be carried vertically up immediately over the top of the fire. Theoretically that was an excellent idea, but unfortunately in practice, especially in houses of several stories, it could not be given practical effect, because in most houses the fire-place openings on the upper floors were immediately over those below, and it was necessary in order to get the flues up to carry them over in the manner which was common practice all over the country. In conclusion, he wished once more to thank Mr. Dufton for having given a highly interesting paper, and one which they had all thoroughly enjoyed.

Mr. W. E. Fretwell desired to supplement his previous remarks by relating an experience of an unusual character. He was puzzled by the ineffectiveness of a boiler-chimney in a school. When he went to investigate he found that the smoke was coming out of the adjacent chimney. It proved that two chimneys had been run down side by side and connected somewhere near the bottom. The difficulty was got over by stopping one of the chimneys.

Mr. W. A. Young said that thirty years ago he built a house on a hill in an exposed part of the country, and found it during the first winter subjected to very strong winds. The next year he put in a small boiler by the side of the range. He put it in the kitchen, and delivered the products of combustion immediately above the register of the range. It proved to be entirely satisfactory, and they had not had an open-fire in the house for more than thirty years. The heating was supplemented by a gas-fire in the central hall. Anthracite was used for a time, but it proved troublesome. In the front room the heating had been supplemented by an electric radiator. He believed that in the small house, with, say, six or eight rooms, it would be found to be quite practicable to heat by means of central heating, with radiators and boiler, and to do this without a cellar if necessary. He could have had a cellar dug if he had wanted it, but the kitchen was always comfortably warm and no more.

In conclusion he wished to thank the Council very cordially for placing his name upon the Life Membership. It had been a source of great satisfaction to him as a journalist to attend the meetings, and next to the appreciation which his firm had accorded to him on his retirement he had appreciated nothing so much as the action of the Council in making him a Life Member.

Mr. C. A. Masterman said that Mr. Dufton in his paper had covered an historical epoch ranging from early times when even on an open-fire it was possible by redesign to save five-sixths of the fuel, to the modern other extreme of heating appliances used without flues. This latter condition he suggested was unsatisfactory, whether the source of heat was by hot-water radiators, gas heaters or electric heaters. In was a familiar experience to find people condemned to live in such unventilated rooms, gradually growing very dissatisfied with the conditions without precisely being able to give the reason why. The determination of the reason why appeared to be a right and proper subject for the Institution to investigate.

Mr. Dufton had referred to Monsieur Gauger as a leading scientist of his day dealing with these matters, and showing an intelligent anticipation of the need for the eupatheoscope. He (Mr. Masterman) would suggest that Mr. Dufton, evidently himself being a reincarnation of Monsieur Gauger, should take a leading part in the deliberations and investigations connected with the problems created by modern flueless buildings.

Mr. A. F. Dufton, in replying to the discussion, thanked the members for the very kind way in which his paper had been received, and for the interesting discussion which it had evoked. The discussion had been more interesting than the paper itself. It had been suggested that the Institution ought to discourage the use of the open-fire, though he was glad that this had not been the unanimous suggestion. Perhaps he might quote a remark made some years ago by a Past-President of the Institution who was present that morning: "Depend upon it, the affection of the average Englishman for a blazing open-fire, although he may not be aware of it, has, apart from its wastefulness, a sound scientific foundation, and I feel that the objections to central heating often freely expressed, are frequently justified."

He hoped that in making this paper rather light he had not obscured the issue. The principle of the ventilating fire-place was good and it was one reason why he wanted to build a house and move from his present one. Once a house had been built it was extremely difficult to get in a proper system of ducts, if these had not been provided. A house should be built with proper ducts as a matter of course. He knew of houses which had been built with ducts after the Galton plan so that the incoming air went up inside the chimney-stack and the warmed air was introduced above the chimney breast. The result was very satisfactory: there was no cold air to nip the backs and heels of those sitting before the fire. A fire in the drawing-room should draw fresh air from outside, which should be warmed and delivered to the room. It should not draw the smell of cooking from the kitchens.

One thing about the discussion which he particularly appreciated was that it had raised very few points for him to answer, and again he wished to thank them for the way they had received his paper.

The President read a telegram which had been received from Mr. Stott, a Past-President, sending best wishes for a successful meeting. He added with regard to the Benevolent Fund, that they were quite anxious to receive any offers of donations towards that Fund from any of the members present at the meeting, and if they would communicate with him or with Mr. Watt their offers would be very welcome.

He called upon Mr. Potterton to move a vote of thanks to Mr. Dufton.

Mr. A. B. Potterton said that before he proposed a vote of thanks he wished to say that he could not agree with Mr. Mumford Bailey in regard to dispensing with the fire-places in rooms.

He advocated the provision of a fire-place in every room, although there may be central heating, as in the case of living-rooms an open-fire is pleasant, and in bedrooms and others only used occasionally or for a short period, a gas-fire soon raised the temperature if necessary.

He had found that the housewife preferred not to depend on central heating only for warmth, as this usually gave a feeling of stuffiness to the rooms.

With regard to the paper, he had much pleasure in proposing a hearty vote of thanks to Mr. Dufton. The paper had brought out many points, and one which had interested him especially was the smoke-shelf. This was new to him, but he could quite appreciate its value in preventing the rain from dropping into the fire, also assisting the progress of the smoke up the chimney.

Mr. S. Naylor seconded the vote of thanks and took occasion to say a word about the Benevolent Fund. He said that he noticed that the President and Vice-President had contributed a total of 75 guineas already, and he wished to put his own name down as one of the contributors to the extent of ten guineas.

With regard to the paper, it had been a great pleasure to hear. It was devoid of technicalities, and yet full of very useful information. He lived in a sixteenth-century house, and across the front of the fire-place was a piece of stained glass window. Various chimney-pots and cowls had been tried, but they still suffered from smokiness. One man in Sheffield guaranteed to cure the trouble by putting on a special form of cowl, and he accepted his offer and told him that he would pay him when it was cured, but he had heard no more. The chimney was one of the old-fashioned type up which a boy could be put instead of a brush. But by closing the aperture to a large extent and fixing a new grate all the discomfort was removed.

The vote of thanks was carried by acclamation and briefly acknowledged by Mr. Dufton, following which the meeting terminated.

Building Research Station, Garston, Nr. Watford, Herts.

METALLIC WALL-PAPER

By A. F. DUFTON, M.A., D.I.C.

In a paper on " Radiant Heat " read before the Institution in November 1932, some of the possibilities opened up by the use of metallic wall-paper were touched upon. It was pointed out that, in a room with two internal and two external walls, the outward transmission of heat through the external walls causes their inner surfaces to be colder than those of the internal walls and tends to lower the equivalent temperature in the room.

It was suggested that if these inner surfaces of the external walls were covered with metal foil they would act as reflectors, and that the occupants of the room should feel thermally as if the room were bounded not by the external walls but by the images of the warmer walls reflected in them.

The advantage would be twofold : the loss of heat from the room would be reduced and greater warmth would be experienced.

An opportunity has now been taken of investigating this possibility experimentally and of obtaining a measure of the effect. The experiments have been carried out in the experimental house at the Building Research Station, which was designed to give conditions as closely similar as practicable to those existing in a pair of semi-detached houses, and which was described in the *Journal* for April, 1933.

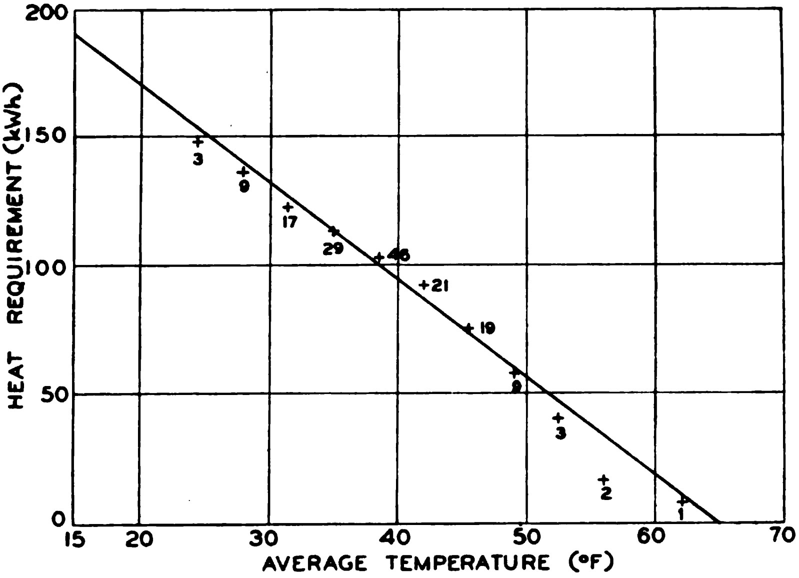


FIG. 1. WITH METALLIC WALLPAPER.

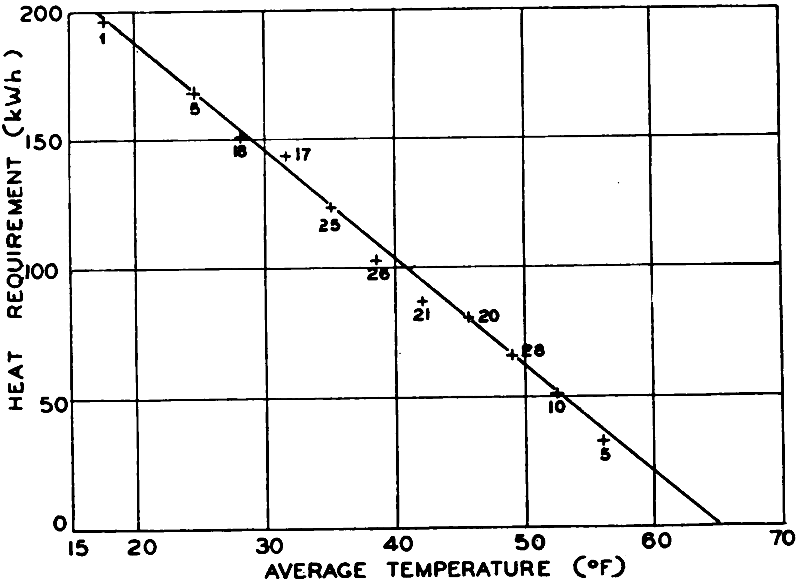


FIG. 2. WITHOUT METALLIC WALLPAPER.

The inner surfaces of the external walls of the rooms were covered with a paper with an aluminium foil surface, and during the past winter the rooms of the experimental house were kept day and night at an equivalent temperature of 65° F. by electric stoves which warmed the air in the rooms. The windows of the rooms were kept closed, and in the staircase annexe the air was heated and maintained at an average of the air temperatures in the four rooms of the house. As in a comparable previous heating season, when the walls were not covered with metal foil, the rooms of the house were used as laboratories, care being taken to avoid undue interference with the investigation and allowance being made for the heat contributed by the occupants of a room. The daily heat supply to each room from 9.30 a.m. to 9.30 a.m. was measured.

The comparison of the daily heat requirement of the four rooms with and without the metallic wall-paper has been made on the basis of the average outside shade temperature. In Fig. 1, the heat requirement is plotted as a function of this average temperature, the observations being grouped in intervals of 3½° F.; the number of observations in each group is shown. In the present experiments the daily requirement was found to be 3.8_0 $(65 - T)$ kWh., where T° F. is the average outside shade temperature, while in a previous season, with the same type of heating, but without metallic wall-paper, the daily requirement was 4.1_4 $(65 - T)$ kWh. (*cf.* Fig. 2).

The experiment shows, therefore, that this use of metallic wall-paper resulted in a saving of heat amounting to 8 per cent.

The experiment was not carried out with a view to advocating the use of metallic wall-paper but merely in order to confirm a suggestion made upon theoretical grounds and to illustrate the influence of the temperature and nature of the wall surfaces upon the equivalent temperature of a room.

It may perhaps be mentioned that if it were desired to use a metallic wall-paper in this manner it would be possible to obtain uniformity of appearance by papering *all* the walls of a room and, while retaining the sight of the metal foil upon the inner walls, to diminish its reflecting power for radiant heat by a coating of lacquer. It will be remembered that Leslie found that a lacquer coating one-thousandth of an inch thick diminished the reflecting power of a tin mirror to one-fifth of its original value.

ABSTRACTS

Quick Freezing of Foods. 621.566

The amount of heat to be removed from the product consists of the sensible and latent heat of the water content plus the sensible heat of the remainder of the product. In addition to this heat removed from the actual product, there may be also heat from packages, pans, cans, various machinery, lights, door openings, leakage through walls, etc., dependent upon which particular system or process is used. It is considered conservative practice to figure the total heat to be removed during quick freezing as the equivalent of the sums of latent and sensible heat units necessary

APPROXIMATE AMOUNT OF HEAT ABSORBED IN LOWERING THE TEMPERATURE OF THE WATER CONTENT OF FOOD PRODUCTS FROM + 60° F. TO – 5° F.

Product	Percentage of water, average	Heat absorbed per lb. of product in B.T.U.
Distilled water	100	189
Berries and Fruit—Edible Portion		
Apples	85	161
Cherries	81	153
Cranberries	89	168
Peaches	89	168
Pineapples	89	168
Raspberries	86	163
Strawberries	90	170
Vegetables—Edible Portion		
Asparagus	92	174
Lima Beans	69	130
String Beans	89	168
Carrots	88	166
Corn	75	142
Peas	74	140
Poultry (dressed)		
Chickens (broilers)	44	83
Fowl	47	89
Geese	39	74
Turkeys	42	79
Shell-fish—Edible Portion		
Clams	86	163
Lobsters	79	149
Oysters	87	165
Fish Fillets		
Cod	83	157
Haddock	82	155
Halibut	75	142
Mackerel	73	138
Salmon	65	123

to remove in cooling from + 60° F. to – 5° F. a weight of water equal to that of the product desired frozen. In the case of products with a large percentage of fat or bone, an ample safety factor must be added. This is best obtained by experience. (*Bull. Heating, Piping and Air Conditioning Contractors Nat. Assoc.*, March, 1934.)

Heat Emission from Human Beings. 613

According to Doctor Benedict, the human body, being a living machine, is obliged to expend a certain measure of energy simply to keep alive. The measure of this resting energy consumption is the measure of one's basal metabolism, which is simply a base line from which to determine the extra energy required in the performance of particular tasks calling for physical or mental effort. Although the basal metabolism of every individual is different, the heat production for the average man in a group of 100, when lying quietly in bed after breakfast, is about one calorie per minute. This is equivalent to about 238 B.T.U. per hour. Just sitting up increases the energy consumption, and consequently the heat output, by 5 per cent. Standing results in an increase of 10 per cent., a brisk walk will increase the base figure by 200 per cent., and work to the limit of endurance will increase it 1,000 per cent. or more.

It must be borne in mind that a heavy man gives off more heat in support of basal metabolism than a thin man of the same height. A tall man expends more than a short man of the same weight. A man of 25 years of age expends more than a man of 70.

The sex, too, is important in these calculations, since a man's basal metabolism runs about 10 per cent. higher than that of a woman, even though the weight, height, and age are the same. Consequently, in calculating the air conditioning load, consideration should be given to these factors, if the human load consists of predominantly one or the other of the above-mentioned types rather than of average types.

HEAT EMISSION FROM HUMAN BEINGS.

	Emission, average in B.T.U. per hour.	
Activity	Earlier Tests	Recent Tests[4]
Lying in bed	—	238
Sitting down	384[1]	250
Standing	431[1]	262
Brisk walk	1731[2]	714
Limit of endurance	2555[3]	2618

The accompanying table gives the heat emission of human beings engaged in various occupations, as reported by previous and these recent tests. (*Heating and Ventilating*, May 1934.)

---

[1] Reported by Houghton, Teague, Miller & Yant at A.S.H.V.E. Research Laboratory.
[2] Reported by Douglas, Haldane, Henderson & Schneider.
[3] Reported by Bendict & Carpenter for " Very severe exercise."
[4] Reported by Dr. and Mrs. Benedict, Carnegie Institution.

HEATING AND VENTILATING INDEX

Oil Fuel. 621.183.57

Automatic Oil Burner Installations. 3 pp. Dealing with the calculation of oil consumption for steam boilers and dual heating and hot-water supply boilers : *Heating and Ventilating Engineer.* April 1934.

Ventilation. 622.46

Ventilation Testing Instruments and Their Uses. A. T. Henly. 3¾ pp., 7 illus. Describing orifice fitting, manometer, the kata-thermometer, with directions for use : *Heating and Ventilating Engineer*, April 1934.

Ventilation. 697.9

The Students' Text Book of Heating and Ventilation. Norman Wignall. 2½ pp., 2 illus. Dealing with methods of ventilating, by chimney, ventilating cowls and upward and downward systems : *Heating and Ventilating Engineer*, April 1934.

Corrosion. 621.196.5

Korrosionsschutz bei Warmwasser-Versorgungsanlagen. Erich Naumann. 5 pp., 3 illus. Dealing with prevention of corrosion in hot water supply apparatus : *Zeitschrift des Vereines Deutscher Ingenieure*, April 14th, 1934.

Refrigeration. 621.56

Air Conditioning for Heating Contractors. Charles E. Tolton. 2 pp. Dealing with safety precautions against toxic vapours which escape from the system and danger of vapours exposed to open flame : *Bull. Heating, Piping and Air Conditioning Contractors Nat. Assoc.*, April 1934.

Radiant Heating. 697.4

Radiation. Leslie Rayner. 2 pp., 2 illus. Dealing with panel heating systems and method of empirical calculation : *The Plumber*, May 1st, 1934.

Water. 621.194.3

The Use of Sodium Aluminate in Boiler Water Treatment. H. N. Bassett. 2 pp. Explaining how sodium aluminate has advantages over the lime soda process : *The Steam Engineer*, May 1934.

District Heating. 621.312

District Steam Heating. B. M. Conaty. 2½ pp., 3 illus. Dealing with the history and development of district steam heating in the United States : *The Steam Engineer*, May 1934.

Expansion Tank. 697.4

Le Vase d'expansion dans les chauffages à eau chaude. R. Chassereau. 3 pp., 5 illus. Dealing with expansion tanks in hot water heating, necessity of circulation, connections and capacity : *La Couverture Plomberie*, April 1934.

District Heating. 621.312

Les Relations du Chauffage Urbain et du Chauffage Central. Ph. Schereschewsky. 11 pp., 8 illus. Dealing with the relation of district heating and central heating, transport of heat, and use of the heat inside buildings : *Chauffage-Ventilation*, April 1934.

Refrigeration. 621.566

Air Conditioning for Heating Contractors. George H. Dickenson. 9 pp., 3 illus. Dealing with calculations for mechanical refrigeration : *Bull. Heating, Piping and Air Conditioning Contractors Nat. Assoc.* March 1934.

Trains. 625.234, 697.96

Comfort Cooling on Wheels. F. L. Sahlmann. 9 pp., 7 illus. Review in detail of methods, accomplishments and prospects : *Refrigerating Engineering*. May 1934.

Air Conditioning. 697.9

Air Conditioning in the Making of Rayon. W. C. Giles. 1¾ pp., 1 illus. Describing process of manufacture and air conditioning necessary. *Refrigerating Engineering*, May 1934.

Fuel. 621.183.57

Study of Fuel Burning Rates and Power Requirements of Oil Burners in Relation to Excess Air. L. E. Seeley and E. J. Tavanlar. 4 pp., 9 illus. Describing research on operating range of oil burner in relation to maximum and minimum oil burning rates with varying proportions of excess air : *Heating, Piping and Air Conditioning*, May 1934.

Boilers. 621.184

Design and Valuation of Cast Iron Domestic Heating Boilers. Charles W. Brabbée. 6 pp., 22 illus. Describing fundamental studies during the past 25 years : *Heating, Piping and Air Conditioning*, May 1934.

Air Conditioning. 697

A Test House for Air Conditioning Units. Gordon Thompson. 4 pp., 7 illus. Describing construction, air change, sun load, enclosure, " weather " mechanism, temperature measurements and control equipment : *Heating and Ventilating*, May 1934.

UNIT HEATING INSTALLATIONS

By F. M. WARE (Associate Member)

ASSOCIATE MEMBERS AND GRADUATES SECTION

BIRMINGHAM, MARCH 14th, 1934

THE warming of buildings by means of installations comprising a number of unit heaters, suitably distributed, and served by means of steam or hot water mains, is rapidly growing in favour in this country, particularly for buildings of the industrial type.

Comprehensive tables and data have been issued by the leading manufacturers of these products, indicating the performances of the various types and sizes of unit heaters, and there is no difficulty in selecting machines having outputs to suit individual conditions and requirements.

It is therefore my purpose, in presenting this paper, to give, in a practical manner, an outline of the opinions formed in the course of my own experience in handling this particular class of work.

The main advantages to be gained by the adoption of unit heaters, comparative to direct radiation, are as follows: (1) Warmth is evenly distributed and circulated near floor-level and within the working zone.

This is one of the outstanding advantages of unit heating, since, with direct radiation, it is seldom convenient to situate the radiating surface in any position other than overhead. (2) Where steam is available, rapid warming-up is obtained, provided always that the steam and condense mains are of adequate capacity to deal with the initial higher output of the unit heaters, and free drainage of condensate maintained.

Further, in cases where a building is only intermittently warmed, considerable economy in fuel would result, owing to the fact that the steam-content of the mains themselves is very small, whilst with a low-pressure hot-water job, consisting, say, of overhead pipes, the heat initially absorbed by the water in raising the required surface temperature, always very considerable in amount, is entirely wasted.

Owing to the low thermal content, time-lag is greatly reduced, rendering the unit-heater installation particularly suitable for thermostatic control.

(3) In order to keep low the cost of factory buildings, they are now, usually of very light construction, frequently steel-framed and lined along walls and roof with asbestos sheeting or protected metal.

These particular building materials are highly heat-transparent, and if hot radiating surfaces are installed in close proximity to same, heat will be much more rapidly transmitted to the external air than would be the case where unit heating is employed. (4) If the unit heaters are coupled to the outside air by means of suitable steel ducting, with a recirculating damper, they can in summer, be employed for the purpose of introducing and circulating a supply of cool air into the building.

A few remarks upon the types of unit heaters now commonly met with will not be out of place.

Industrial Floor Type.

This consists of a heater battery contained within a cylindrical sheet-steel casing, air being blown by means of the fan, over the battery, and discharged near floor-level through the bottom of the machine.

This type is particularly limited in its practical application owing to the fact that it is suitable for dealing with isolated areas only, and does not lend itself to any scheme whereby the warmed air can be kept in constant circulation.

Cabinet Type.

This consists of a rectangular steel casing containing a heating battery through which air is drawn by a centrifugal type fan and distributed at a velocity of about 1,500 ft. per min. above the heads of the operatives, the return circuit of the air being along the floor-level, thence to be drawn again over the heating battery and recirculated.

The main disadvantages of these heaters is that owing to their great air output and high velocity, if the battery should be shut-off or become water-logged, and the fan left running, strong and objectionable draughts are soon felt.

Suspended Type.

What is by far the most popular and adaptable type of heater unit, is that usually known as the " suspended type."

This consists of a battery of copper-finned tubes with collecting headers, enclosed within a sheet-steel casing having adjustable louvre plates on the discharge face, for the purpose of exercising control in the directional route of the warm air.

The motive power usually consists of a motor-driven fan mounted at the rear of the assembly.

These, again, may be divided into two types, those having a square outlet face and a single fan and motor, and those having an oblong horizontal face and two motor fans.

The outlet velocity of this type of unit heater is usually in the region of 900 to 1,200 ft. per min., at which velocity the output will be about three times as great as would be obtained from the battery without the use of the fan.

The great advantage attaching to this particular type of unit is its low cost, and the fact that by reason of its moderate output in comparison to the cabinet type, a better distribution of heat can be obtained by the use at a competitive figure, of a larger number of units.

Selection of Units.

When selecting a unit heater, particular attention should be paid to the final temperature of the warm air delivered. Within reasonable limits the lower the final temperature the more positive is the movement in the desired direction. This point is of particular importance in lofty buildings where the units have frequently to be fixed at a greater height than that which is considered advisable by the manufacturers themselves.

It also follows that, for a given output in B.T.U., the lower the final temperature, the greater will be the quantity of air delivered, an important consideration where the units are to be used during the summer months for ventilating purposes.

Disposition of Units.

When preparing the layout of the units, it is advisable that they should be allocated to such positions from which they may deliver towards the outside walls of the building in an oblique direction. This will eliminate to a large extent cold spots and draughts through doors and windows. It is most important that the arrangement be such that a continuous current of air is moved right round the building. Generally speaking, the units should not be situated at a height greater than about 15 ft., except in the case of the largest sizes, where I have known them to be fixed with entirely satisfactory results at a height of 20 to 22 ft.

It is my own experience that unit heaters having a face area of less than 15 in. by 15 in. are unsuitable for industrial heating, but may usefully be employed in small rooms or workshops where the height is not too great, or where length of range is not required.

When dealing with long narrow buildings care should be taken to ensure that the units are not situated on the longer walls, to blow towards the opposite side, as this will surely result in cold spots, and possibly down-draught.

Layout of Mains.

When employing steam as the heating medium it is usual for the steam and condense mains to be fixed above the roof trusses, the unit heaters being suspended below same.

It will be readily appreciated that when the installation is based upon output with recirculating air, the intitial steam consumption when starting up will be much greater than on normal operation, owing to the lower temperature of the air passing through the units, and both steam and condense mains must be capable of dealing with the starting load, if rapid heating-up and constant steam pressure are to be obtained.

The steam service to each unit should be taken direct off the top of the main to ensure dry steam being obtained and the condense should be trapped and lifted back into the top of the condense main, from which point a gravity flow back to the hot-well should be arranged.

The two-pipe open-return system is undoubtedly the most satisfactory in operation, and in my experience, the best all-round performance is to be obtained at pressures between 15 and 30 lb. per sq. in., which can readily be maintained without too constant attention to the boiler plant. It will be found that it is unwise to base upon the higher pressures of, say, 80 to 120 lb. per sq. in., as these in practice are seldom constantly maintained with the average type of boiler plant used on factory jobs.

It will be found that when employing the lower pressures one or two extra unit heaters will be required to obtain the necessary output, but this extra will be approximately counterbalanced by the reduced cost of the boiler for the lower pressure.

When dealing with lofty buildings, having a considerable amount of roof glazing, it is advisable to provide a pipe coil directly under the glazed surfaces to reduce down-draught. This surface can usually be obtained by a suitable layout of the steam mains themselves, without calling for any special pipe coils.

Where hot water is used as the heating medium, it is necessary, on installations of any magnitude, to incorporate an accelerator pump, so that the sizes of the distributing mains may be kept within reasonable and economic limits.

Electrical Control Gear.

Each unit heater should be provided with a separate ironclad switchfuse unit so as to obtain independent isolation at each point in case of emergency or breakdown.

The unit heaters lend themselves particularly to thermostatic control, owing to the reduction of the time-lag brought about by the lower thermal content of the apparatus itself, and any number of units can be controlled by means of a single thermostat inserted in the leads to the main distribution board.

If an automatic oil burner, or mechanical stoker, is employed it is quite a practical proposition, by installing an electrically-driven feed-pump operated by an electric float-switch controlled by the actual working level of the water in the boiler itself, to obtain what may, in every respect be termed a "fully automatic plant."

If thermostatic controls are employed, care must be taken to see that they are placed in such a position as to be clear from impinging draughts, failure in this respect may lead to serious wastage of fuel through the heaters cutting in unnecessarily.

In closing, a few remarks about fuel and electrical consumption will no doubt be expected.

It is, unfortunately, difficult to get a client to furnish one with actual running costs, and for this reason, I am unable to furnish any actual figures.

It must, however, follow that the fuel consumption will be lower than with direct radiation owing to the fact that the heat is kept largely within the working zone, and by the reduction in heat losses to be effected owing to the elimination of hot radiating surfaces against external walls, etc.

Electrical consumption is very small, almost negligible in relation to the amount of heat delivered by the unit heater.

As an instance, a unit having a ½ h.p. motor consuming about 400 watts per hour, when supplied with steam at 30 lb. per sq. in., will deliver up to about 400,000 B.T.U. per hour. Furthermore, in order to obtain electric current for trade processes at a low rate, most industrial concerns take current in bulk, and frequently do not reach, in the ordinary way of business, the scheduled minimum consumption upon which their rate per unit is based, so that the current used will, in many instances, entail no extra cost to the consumer. There are on the market one or two makes of units which employ electrically-heated elements as their heating medium, but, owing to the present high cost of electricity when employed for heating, the claims of these cannot be considered seriously, except perhaps for warming retail shops.

If, in the future, the cost of current for heating purposes can be reduced to such an extent as to make it a near competitor of solid or oil fuel, it would appear that the future trend of heating would be in that direction.

THE CASE FOR THE PRIVATE PLANT

By E. G. PHILLIPS, M.I.E.E., A.M.I.Mech.E. (Member.)

PAPER READ BEFORE THE INSTITUTION OF ENGINEERS-IN-CHARGE.
LONDON, JANUARY 10th, 1934.

To talk to Engineers-in-Charge on this matter savours somewhat of " preaching to the converted," but if the subject is unsuitable I have the consolation of being able to blame your Secretary or your Council, as the title was selected for me and was not of my own choosing.

To refer to the case for the private plant infers that there is also a case for another source of power, and it may be advisable to comment generally on this position before proceeding with the main subject.

The alternative supply is obviously the purchase of electrical energy from the authorised supply undertakers, or, in short, from the national grid via either the municipal or private power company's distribution systems. It is not my intention to express any personal views on the " grid " except to say that while the interconnection of selected stations and the operation of plants at their most economical load is technically correct and has much in its favour, yet while the Central Electricity Board is unable to lift the sales' policy from the sphere of politics and local influences, the whole scheme will be handicapped and the maximum benefits will remain unobtainable.

The diversity of opinions held by the supply authorities prevents even a standard price for standard conditions, and while this state continues the private plant will always have an easy field and will flourish longer than might otherwise be the case. The present official attitude, to condemn the private plant almost without regard to the question of its thermal efficiency and other matters having a definite bearing on the reactitude of the decision, cannot be justified, and is, in fact, harming the cause of those who refuse to consider co-operation or to recognise that in many industries the " condensing " prime mover can never compete with the private plant.

Cheap power or electrical energy must be recognised as the life blood of most industries, and it should be the first consideration of the " powers that be " to assist in providing " a cheap and abundant supply " of this essential commodity without regard as to the effect upon the National Scheme of which they were the sponsors.

It is no adverse comment to remind you that the thermal efficiency of the selected stations only averages about 20 per cent., and there is only one steam station having a thermal efficiency reaching a 23 per cent. efficiency. As engineering design now stands, practically 80 tons of every 100 tons of coal consumed in our "super-power" stations is dissipated to the atmosphere, or the river, or lost in one form or another.

Great scientific care and control is exercised in the boiler house, and in consequence, efficiencies as high as 90 per cent. are being obtained, and yet when this efficiently produced steam passes into the turbine room the thermal efficiency drops to the low figure of 20 per cent. as already mentioned. This loss is, of course, due to the inability of the plant to make any really effective use of the latent heat in the steam, and at present there is no sign that this valuable property of the steam will be usefully employed.

In Manchester and a few other towns there are very interesting examples of the sale of heat as well as energy, and in such instances the thermal efficiency is, of course, much in excess of the figure given, while the revenue derived from the sale of heat greatly exceeds that obtained from the sale of electricity.

Unfortunately, the necessity to be able to "drown" huge quantities of heat has caused the large generating plants to be located on the banks of the rivers and frequently far from any centre in which a ready sale of heat could be effected. One sometimes wonders if the old "Central" stations which were "centrally" located in the cities and towns could not have justified their continuance if only attention had been directed to the "commercial" advantage of selling heat as well as energy. The ability to purchase heat for use in the large buildings that surrounded these stations would have been much appreciated, as it would have eliminated the necessity for innumerable boilers and heating plants with their low efficiencies, the carting of coal and ashes, with the attendant dirt and dust, etc.

Turning now to the position as it confronts the industrialist who requires cheap power, he has the following alternatives :—

(*a*) Purchasing his requirements from an outside source, at terms which are usually highly scientific and not commercial; that are subjected to change due to political influence, and which impose upon him penalties and restrictions over which he has little, if any, control.

(*b*) Instal his own plant in conjunction with, or separate and apart from, his process, and determine how it can be run as an asset to and in co-operation with his one particular aim in business—the cheap and rapid production of his specialised product.

The decision will be affected by many things, such as :—

(1) What is the general practice in his particular trade, and what are his competitive costs for power and heat, etc.?

(2) Are any waste products available such as "process" steam, trade refuse, water power, etc.?

(3) Can he combine with a neighbour who requires what he has to reject?

(4) Is the public supply available at cheap rates continuously, or must he reorganise his process to meet the restrictions imposed, and can this be done without detriment to his business?

May I at this stage confine my remarks to industries and institutions, etc., in which heat enters largely into the necessities of the "process" or building. It can be stated that, generally speaking, all boilers installed in these establishments are required primarily for the purpose of raising steam to be used as a conveyor of heat. Steam is a very flexible and convenient method of carrying heat from one point to another, and I repeat that steam is usually generated and utilised primarily for this purpose. This being so, it will not be a very great exaggeration to say that in a "process" demanding considerable quantities of heat either for boiling, evaporating, heating or drying, etc., that steam would undoubtedly have to be generated even if electricity were available at an exceptionally low figure.

Properties of Steam.

Steam has two important properties, i.e., kinetic energy and latent heat. Generally speaking, the former is due to the pressure, and the latter is the heat required to convert water from a liquid to a gaseous state without raising its temperature. While one B.T.U. will raise one pound of water through 1° F. up to a temperature of 212° F., yet it will require 970.7 B.T.U. to convert that one pound of water at 212° F. into one pound of steam at the same temperature. Naturally, to re-convert one pound of steam at atmospheric pressure (212° F.) to a pound of water at the same temperature, the 970 B.T.U. will have to be extracted either by transferring them to some useful process or dissipating them to the atmosphere or to the cooling water of a condenser.

If, therefore, our original pound of water was at a temperature of 32° F., it will have required 1,150 heat units for its conversion to atmospheric steam, of which 970 are "latent," and only 180 sensible; the value of the latent heat, therefore, cannot be exaggerated, and it is the loss of this valuable property that prevents the super-power station from being really efficient thermally.

The additional heat necessary to raise our pound of "atmospheric" steam to an appreciable pressure is almost insignificant, as while the former has a total heat content of 1,150 B.T.U., yet at 100 lb. (gauge) pressure the heat content is only 1,192, and at 150 lb. pressure it is 1,201 B.T.U. The cost of producing " pressure " is therefore low, but the kinetic energy value of the steam materially increases with this " low cost " pressure.

If this foregoing statement had been followed it will now be appreciated that in any industrial process, large institution or hotel, etc., where both power and heat are required—it should be possible to obtain *both* from the one supply of steam by first passing the steam through an engine or turbine, developing power by reducing the pressure, and then utilising the exhaust steam at any pressure necessary for the " process," and extracting the latent heat therefrom. A " combined" plant of this type can readily be operated at a thermal efficiency of 60/70 per cent. against 20 per cent. efficiency of the public supply, which is also subject to the further losses incurred in distribution, transformation, conversion, etc.

Exhaust Steam Pressures.

All the foregoing is probably well known and fully appreciated by all present, but it is not usually so readily recognised that for many processes, such as boiling, evaporating, drying, cooking, etc., similar results are obtained by employing low-pressure exhaust steam as when using high-pressure steam direct from the boilers. Naturally, if high temperatures are essential, then high pressures are also necessary, but as the difference in total heat content is so small, then I repeat that all the above " process " work is as readily carried out at low pressures as at high.

Failure to recognise that the volume of the steam increases enormously as the pressure is decreased has frequently caused certain engineers to abandon the obvious advantages of using low pressure instead of the more common pressures for their various processes. Success is only possible when the same weight of steam is supplied to the plant in the same period of time, and as the volume is so much greater at lower pressures, then obviously the pipe areas and the square feet of heating surface must be augmented if the additional volume to give the same weight of steam, per unit of time, is to be available.

Unfortunately it has to be admitted that manufacturers of such plant as boiling vessels, steam jacketted pans, air heaters, cooking plant, dye barks, evaporators and similar apparatus usually designed for the use of high-pressure steam, simply to be able to reduce the selling cost to the minimum. It is to be regretted that designers of plant should have to consider primarily the selling cost and forget the efficiency and cost of operation. A recent example was the purchase of an air heater for use in connection with the drying plant for a large industrial laundry. In the first place an electrically-driven fan was put forward because the motor would only cost, say, £25, while a steam engine would be probably 300 per cent. in excess of that figure. When a desire for a steam engine was expressed, the ordinary high-speed, lubricated type of engine was put forward, and arranged to exhaust to atmosphere ; after having suggested that the engine should exhaust into the air heater, it was first argued that this would necessitate a larger heater, costing more than the one originally offered, while it was definitely condemned on the grounds that the cylinder lubrication would be carried over with the steam and would choke the heater and render it non-effective.

Eventually, definitely specifying a non-lubricated high-speed engine capable of developing the necessary power against a back-pressure of 3 lb. per sq. in., together with an air heater capable of taking the whole of the exhaust steam and supplementing it with high-pressure steam thermostatically controlled, resulted in the firm which was previously offered the order refusing to quote for many reasons, among them being that the initial cost would be high—" the non-lubricated engine was an experiment," and that exhaust steam was too wet for use in an air heater. My contention is that makers of this type of plant should only sell high-pressure heaters and electrically-driven fans, etc., under protest, and should definitely standardise equipment of high thermal efficiency and low running cost. This policy would necessitate the education of the trades involved, so that the purchaser would recognise the value of the " latent heat " and refuse to be a party to the wicked dissipation of so valuable an asset.

Energy Content of Steam.

Naturally, the amount of power which can be obtained from a given weight of steam is proportional to the initial pressure and the back-pressure against which the prime mover has to exhaust, and the following table may be of interest, showing the b.h.p. obtainable from 10,000 lb. of steam per hour against various back-pressures.

Inlet Pressure	Exhaust Pressure in lb. (gauge) per sq. in.						
	0	5	10	20	30	40	60
50	235	200	—	—	—	—	—
60	260	225	190	—	—	—	—
80	320	275	240	165	—	—	—
100	350	330	280	225	175	130	—
150	440	410	370	310	270	210	145
200	470	445	420	365	320	275	205

It will be recognised that frequently in designing plants of this description, certain complications arise due to the non-synchronising of the steam and power demands ; or where the demand for " heat " is less than that made available by the power plant, but these difficulties are readily met by various methods, such as :—

(*a*) The " pass-out " turbine.

(*b*) Running a back-pressure and a condensing unit in parallel and balancing the load according to the " heat " requirements of the process.

(*c*) Storing surplus " heat " against future " peak loads " in the form of hot water or other liquor according to the industry concerned, etc.

The " pass-out " unit can be designed to meet all requirements from " all-condensing " to " all pass-out," and the control is fully automatic ; there are many advantages in this power unit when the demands for process heat vary greatly and do not synchronise with the power demand.

In many industries the reverse conditions occur, i.e., the demand for process steam or heat is always in excess of that necessary to produce the power requirements of the same plant. Under these circumstances the power unit would be a simple back-pressure unit or units, exhausting into the process main, and the deficiency of steam made up by a relay operated make-up valve which admits just that amount of " live " steam direct from the boilers necessary to maintain the process pressure constant against the varying steam demand and the weight of exhaust steam available from the power plant.

It is under such conditions that the supply authorities should be prepared to co-operate with advantage to themselves and their customers. Where the " process " steam would allow of more power being generated than is required, then surely it should be the correct policy to generate the maximum possible, and to " pump " any surplus into the supply authority's mains ; while, when more power is demanded than the process steam can supply, the customer should be encouraged to generate every unit possible from his manufacturing steam and the rest taken as and when required from the outside supply. This policy differs enormously from that which is now prevalent, when absurd " standby " charges are demanded and which usually absorb the greater portion of the economies effected by operating the " combined system."

A Cost Sheet (Back-Pressure System).

Assume a dye-house or a laundry, a paper-mill or a brewery, a hotel or an institution—any or all of these " industries " *must* instal steam generating plant, as heat cannot be purchased in this country, and the boiler plant, with all its capital costs and running charges is as essential as any other portion of the equipment of the " works." A definite weight of steam per hour must be generated, and even if electrical energy were available free of all cost, these boiler-house charges would still be incurred.

The back-pressure system may necessitate raising the steam pressure somewhat, although it is usually unnecessary. But if higher pressure is required, then the additional coal burned to give the additional pressure is chargeable to the power plant. I am also prepared to admit that from 5 to 10 per cent.—supposedly lost by radiation in passing through the engine—might be quite legitimate as a charge against the power side also. If the plant is a turbine, no oil will be chargeable, while if a reciprocating engine is utilised the same remark applies, providing the steam is not superheated.

Wages can only be a very small item, as the amount of attention on modern plants of the type under consideration is at the most only part time of one man except in the case of very large plants, when a permanent attendant would be advisable.

Repairs and maintenance would be almost nil for the first few years, and then only a few pounds per annum per 100 h.p. of plant installed.

Assume the following conditions, based on a well-known plant :—

Process steam requirements ..	50,000 lb. per hour.
Initial steam pressure ..	190 lb. per sq. in.
Exhaust steam pressure ..	35 lb. per sq. in.
Power requirements, about ..	400 kW.
Public supply costs— lighting 5d., power 1.25d. ..	Average 1.95d. per kWh.
Working hours	52 per week.

In this case two 250 kW reciprocating sets were installed, with elaborate switchboard, etc. The capital expenditure involved amounted to £4,000. (This does not include buildings, the plant being fixed in an existing room.)

The number of kWh generated per week equal 14,000, equivalent to a load factor of 55 per cent. One semi-skilled attendant is chargeable to the plant which runs without cylinder lubrication on wet steam.

The annual cost is therefore as follows :—

5 per cent. on £4,000	£200
7½ per cent. depreciation on £3,800	£285
Labour (one man)	£150
1 barrel crankcase oil, per annum	£6
Repairs and maintenance (first five years)	£20
5 per cent. radiation loss on steam (assuming evaporation of 8 to 1 and coal at £1 per ton)	£105
Total annual cost	£766

Total kWh generated per annum ..	700,000 kWh.
Cost per unit generated	0.25 pence per kWh.
Annual saving compared with the purchase of 700,000 kWh at 1.95d. ..	£5,700.
Return on Capital	142 per cent. per annum.

Note—The municipal tariff has just been reduced to 4.5d. lighting and 1d. power, and the economy will still be about 100 per cent. on capital invested.

Many similar instances could be given in detail, all showing that where boiler plant is already installed and steam is essential, the power requirements can be met—to the limit of the output of the process steam—at figures that cannot possibly be approached by any supply authority, and that the economy is such that the cost of installing the plant is recovered annually. There appears, however, to be no necessity to give these details of specific plants, but rather to make clear the essential factors and the technical data on which every such problem is tackled.

Information as to the weight of steam which must be generated even with power free of cost, the maximum pressure at which it can be produced, and the minimum pressure at which the process can be effectively carried out, gives us definitely the horsepower hours that can be obtained as a by-product from that weight of steam irrespective of the fact as to whether it is sufficient or in excess of the requirements.

Assuming that the " by-product " power capable of being produced is in excess of requirements, then the generating plant will exhaust the whole of its steam into the process main, and the deficiency made up by live steam direct from the boiler through a relay operated make-up valve. Under these conditions the only capital costs will be those for the generating plant modifications to steam ranges, etc., and the running charges will consist of, say :—

Allow 5 per cent. radiation loss on all steam passing through the prime mover.
5 per cent. interest on capital expenditure.
10 per cent. depreciation on generating plant.
Replacement of crankcase oil once per annum.
Labour—from nil to part-time of a semi-skilled labourer.
Repairs and maintenance on engine, which will be found to be almost negligible.

The economies that will be effected will be the whole of the present cost of power and lighting, whether purchased or produced on site by other means.

The alternative view-point is to charge up the total cost of producing the power and light to those services and then to treat the whole of the heat value of the exhaust steam used elsewhere as a by-product of the power plant. Whichever aspect is adopted, it has to be acknowledged that one or other is definitely a by-product of the other, and is very nearly " something for nothing."

The whole of the foregoing is based upon conditions where " process " steam has to be generated without regard to the cost of purchased power, and it is under these conditions where I claim that every possible assistance and encouragement should be given to the installation of plants capable of operating at thermal efficiencies of 60/70 per cent. rather than trying to force their requirements to be met from plants operating at, say, 20 per cent. efficiency.

It is quite easy to prove and for specific instances to be given that economies can be effected and capital expenditure justified on the installation of straight " condensing " steam electric plants as compared with the purchase of electricity from an outside source, but on this occasion I do not intend to press this point.

The industrialist who does not require to burn fuel as part of his manufacturing process ought not to be called upon to find additional capital to run another business in which specialists are already competing, and under these conditions his energies should be devoted to giving the necessary publicity to the reasons why the supply authorities are failing to fulfil their only function, i.e., to provide a " cheap and abundant " supply of electrical energy at a cost which would make it prohibitive for others to start in the same business. This is not intended to suggest that success will immediately follow these efforts, and if failure is assumed, then the internal combustion engine offers the way out.

In spite of the pressure brought to bear upon the Government by the coal industry and by the Electricity Commissioners and other affected interests, resulting in the imposition of a tax on oil, power can still be produced by the internal combustion engine at figures which are of considerable interest and use.

The Diesel Engine Users' Association publish independent figures relating to the costs of operating Diesel engines, and these are quoted as evidence that they readily produce power at very competitive prices. For the year 1931-32 the chief figures are as follows :—

	Air Injection Engines	Mechanical Injection Engines
Total Units Generated	24.2 mill	11.2 mill
Number of Engines	85	29
Kilowatt capacity	23,000	6,500
Engine Hours Run	162,631	73,932
Fuel Oil Cost per Ton (average) ..	69s. 4d.	58s. 9d.
Lubricating Oil per Gal. (average) ..	2s. 7d.	2s. 5¾d.
Cost per kWh *Generated*—		
Fuel Oil	0.245d.	0.205d.
Lubricating Oil	0.032d.	0.045d.
Stores and Water	0.013d.	0.012d.
Wages (running)	0.149d.	0.092d.
Repairs and Maintenance	0.071d.	0.083d.
Total Cost per kWh (generated) ..	0.511d.	0.437d.

As an indication as to the reliability of this type of plant and the faith which important users have therein, it will be recalled that these generating units are installed in such places as :—

The British Broadcasting Station at Brookman's Park (four 300 h.p. engines).
The Crittall Manufacturing Co., Ltd. (seventeen engines in these works).
The Savoy Hotel, London (one 200 kW set).
The A.R.P. Studios, London (two 600 h.p and one 225 h.p.).
Messrs. William Whiteleys, Ltd. (one 300 h.p. set).

The Diesel engine plant is capable of producing power at a running cost of about one halfpenny per kWh, and that indefinitely, and will prove a very serious " thorn in the side " to the public supply authorities, who will have to generate at exceptionally low figures to be able to transform, distribute and sell at a figure to compete with an average running cost of 0.437d. per kWh.

Diesel Steam Plants.

There is no cheaper power available than that produced by the steam engine in which the whole of the exhaust steam and its latent heat is usefully employed.

Where, however, it is not possible to utilise the whole of exhaust steam in the process, then the great economies of this by-product power are easily lost. In industrial establishments the present trend is for the power demand to increase at a greater rate than the heat requirements of the same process and it is perhaps interesting to to glance at the possible advantages of employing both steam and internal combustion units to meet the conditions that may develop from this general trend of conditions.

To increase the capacity of an existing boiler plant so as to provide steam for additional power plant may be an expensive procedure, as the existing buildings, flues and chimney may be unable to take the extra gases. The provision of additional economisers, alterations to flues and the building of a new chimney might also involve capital expenditure and overhead charges difficult to justify, while the inconvenience to the works concerned, while such alterations were carried out, might be of no mean importance.

Under these conditions a complete self-contained Diesel set might more easily be installed and brought into operation and run in parallel with the existing steam plants.

Where lighting forms a considerable proportion of the load and a large percentage of the heat demand is in the form of general heating of buildings and the supply of a hot-water service, it will be recognised that the power and heat demands do not coincide. The peak of the heating load will probably occur early in the morning when the heat losses of the building during the night have to be recovered as quickly as possible, and the demand for steam for this purpose will gradually fall throughout the day as the rooms and even the fabric of the building itself begins to absorb heat, while the minimum demand for this heat will be in the afternoon, when the lighting load is at its peak.

Under these conditions, " live " steam would probably be used to augment that available from the steam power plant for an hour or so in the early morning, while any excess of this exhaust steam—due to the lighting load—would be wasted during the afternoon by being allowed to escape to the atmosphere. The losses for working conditions of this character would consist of :—

(*a*) The generation of steam in the morning from which the kinetic energy was not utilised and only the heat content usefully employed.

(*b*) The loss of the latent heat from all steam rejected to atmosphere, which incidentally would be greater than if a normal steam condensing set were employed.

The so-called " steam consumption " of a " back-pressure " engine is obviously greater per unit of power generated than a similar engine designed to operate at high efficiency by exhausting to a condenser or even to the atmosphere. " Steam consumption " is a very misleading term when applied to an engine or turbine operating against a back-pressure and when the whole of the exhaust is being utilised, as under these conditions, the prime mover has no steam consumption and is acting only as a reciprocating or rotary type of pressure-reducing valve. The steam is not consumed—but only charged in state. When, however, this class of engine operates in such a manner that the exhaust is not fully recovered, then the inefficiency is important and the consumption of steam considerable.

The installation of a Diesel electric set capable of running in parallel with the back-pressure machine would by automatic regulation be actuated by the rise and fall in the exhaust main, and so proportion the load on the steam driven set that at no time would exhaust steam be wasted.

As an indication of the economy that this combination would effect it can be taken that the total cost of the kWh generated on the Diesel would be approximately :—

100 kW	set operating	2,500 hours	per	annum	0.61d.
500 kW	,,	,,	,,	,,	0.42d.
1500 kW	,,	,,	,,	,,	0.34d.

The additional cost due to Capital Charges, etc., brings these figures to :—

100 kW	0.99d.
500 kW	0.70d.
1500 kW	0.55d.

See article by W. A. Tookey, M.Inst.C.E., M.I.Mech.E.

Every case has, of course, to be taken on its merits and it is useless to try and generalise—on figures—when considering a question of such a nature and all that can be stated definitely is that when the power load is increasing and the heating load remaining stationary or decreasing —the Diesel engine cannot be overlooked, and will probably prove the solution of the problem, especially if extensions of steam raising plant offer any difficulty.

Centralisation of generation greatly assists in the lowering of production costs, but the huge capital involved in the transforming and the distributing systems counteracts these advantages and leaves the internal combustion engine a " hot favourite " even if a " cold starter."

There is not sufficient time to make any specific references to prime movers operating on either coal gas or producer gas ; the same principles apply, however, and comparisons will be readily made from published data by those particularly interested in this branch of power production.

It has not been my intention to make out a case for any specific type of plant, but to generally indicate how frequently the economical aspect of a case can far outweigh the scientific and theoretical advantages of a communal supply.

Naturally the supply authorities would contest that there are many advantages allied to the public supply to which I have not referred, and the value of which cannot be expressed in figures.

What, briefly, are the advantages and disadvantages of alternative sources of supply ? The supply authority would claim :—

No necessity for capital expenditure on generating plant and no standby plant required.
No labour for attendance on running plant.
Power always available at a moment's notice.
Continuity of supply.

The arguments against these claims are :—

When 100 per cent. or more can be earned by invested capital it is as well that it should be spent *in* the business as *on* it.

The necessity for standby plant is greatly exaggerated, and modern plant will run almost continuously for years on end without fear of breakdown. The outside authority would greatly benefit if they would welcome acting as " standby " instead of making it prohibitive.

The *additional* labour charges due to running modern generating plant are much exaggerated and unnecessary except on plants of large capacity.

The " always available " claim is true, and when spasmodic overtime in a few isolated departments is frequent the convenience is of considerable value ; but if " process " steam is required at the same time the boiler attendant has to be on duty and the convenience previously outlined is of no value.

Recent experience would suggest that the least said about continuity of supply from the national grid the better.

My business brings me into daily contact with old and fairly obsolete steam-driven plant which has been running almost continuously for half a century, and yet to suggest that continuity of service is jeopardised thereby, meets with no sympathy whatever, and you are invariably told that the works or the institution concerned has never experienced a complete "black out" since the plant was installed. I am of the opinion that the private plant is not handicapped in the contest for continuity of service.

Before concluding this paper I feel justified in drawing attention to the fact that the consumer has definite grievances against the supply authorities as apart from the Central Electricity Board.

I mentioned earlier on that politics had a definite influence on the selling price of electrical energy ; by this I mean that according to the political colour of a municipal authority the policy adopted may be considerably varied. Some councils hold the view that all the services they control should be available to the public at the lowest possible price after full provision has been made for repayment of loans, depreciation and obsolescence, sinking fund, etc., while others are looking upon their trading departments as a ready means of providing funds for the so-called "relief of rates," and fictitious profits are obtained by excessive charges and the surplus handed over to the city treasurer. The difference in these policies accounts for more than 0.5 pence per unit in certain instances.

The supply authorities take no ordinary industrial "risks," and, due to the monopoly powers under which they operate, they are able to impose restrictions and penalties which would not be considered if competition was present. I refer primarily to :—

Maximum demand charges.
Power factor penalties.
Load factor restrictions.
Coal cost clauses.
Wages clause, etc.

It would not be so detrimental to progress if the technical ambitions of the supply engineer could be incorporated in what I would term "commercial tariffs." Why it could be considered *infra dig.* for the electrical engineer to be commercial I cannot understand, but it is on rare occasions only that a simple straightforward tariff, easily and readily understood by the prospective consumer, is available.

Could anyone justify offering a butcher a supply of electrical energy on the following basis? This is a copy of an actual tariff recently quoted to me for a supply to an institution :—

Lighting.

"Where the number of units consumed within one year ending 31st March is less than 5,000, 9d. per unit for the first hour's consumption of the average maximum demand per day per quarter, and 4½d. per unit afterwards.

"Where 5,000 or more units are consumed within one year ending 31st March, 9d. per unit for the first hour's consumption of the average maximum demand per day per quarter, and 3½d. per unit afterwards."

The power tariff is also just as complicated and difficult of understanding, reading :—

"All consumption over 75 units per quarter per horsepower demanded, 4d. per unit for the first hour's consumption of the average maximum demand per day per quarter and 1½d. per unit afterwards."

Restricted Hour Supply.

"Where the consumption exceeds the equivalent of 1½ hours per day, and the consumer agrees to take no supply between the hours of 4 p.m. and 6 p.m. during the four winter months of November, December, January and February, a flat rate of 1½d. per unit."

Another recent tender reads as follows :—

"A rental of £1 per kilowatt per quarter of the consumer's maximum demand, subject to a minimum payment in respect of any quarter's kilowatt demand, equal to 50 per cent. of the previous highest quarterly payment in respect of kilowatt demand, plus :—

"A unit price of 0.35 of a penny per kWh for all units up to 25 per cent. load factor and 0.30 of a penny for all units in excess of 25 per cent. load factor."

Our friend the butcher would presumably state in reply to an inquiry as to the price of meat, that he must refer to the day of the week, the hour of purchase, the proportion of bone and fat, the credit value of the wool or hide taken from the carcase, the cost of hay or the hire of grass land, while his offer would be more favourable if the customer would undertake to train his appetite so as to only require meals at unusual hours.

Conclusion.

In conclusion it seems inevitable that until some unforeseen complete modification of a radical nature occurs in the design of steam-driven prime movers, the thermal efficiency of the supply authorities' plants will remain somewhere within the neighbourhood of 20 to 25 per cent., unless a market can be found for the sale of heat as well as energy.

This being so, then every possible encouragement, both nationally and municipally and industrially, should be given to setting up of equipments capable of being operated at high thermal efficiencies and thereby economising in the consumption of coal and other fuels effecting economies in production costs and the reduction of selling prices with the resulting increase in production.

Industries requiring heat should be encouraged to " sit down " alongside other plants who have enough and to spare, and I would go so far as to suggest that as the super-power station has thought it desirable to locate itself far from the industrial centre, that it should now consider the desirability of enticing heat-requiring industries to come alongside and purchase from them the latent heat of the steam which they now " drown " in the river or dissipate in the high concrete cooling towers, so prominent a feature of these stations.

Complete recognition of the fact that " combined " plants can operate at 60 per cent. efficiency should be a policy of the national supply, and every possible encouragement given to the private plant by absorbing its surplus output, or by providing what cannot be generated without the imposition of restrictive penalties.

Nationally, we live by helping one another, and nothing but good can come of co-operation between the justifiable private plant and the national supply, while any furtherance of the policy that every possible effort must be made to prevent the continuance of the private plant and that no further increase of such stations be allowed, will result in harm to the nation as a whole and the industrialist in particular.

Co-operation is of paramount importance, and full investigation will result in the complete justification of the majority of the private power plants.

MODERN METHODS OF HEAT INSULATION

By CYRIL S. WOODWARD, B.Eng., A.M.I.N.A.

PAPER READ BEFORE THE CERAMIC SOCIETY

STOKE, NOVEMBER 13th, 1933

Before detailing and discussing the various types of insulation, it may be of interest to outline the history of the subject and consider briefly the theory of heat losses.

Historical.

In the year 1769, James Watt took out a patent for lagging the cylinders of steam-engines with wooden laths, although prior to this, instances are on record where Spanish peasants lined the walls of their cottages with cork bark to conserve the heat in their rooms, or conversely to maintain cool conditions during the hot weather. Later, however, various types of clays and earthy substances, animal excreta, straw and grasses were often used.

About the middle of the nineteenth century, the Frenchman, Péclet, set out to investigate the problems of heat transmission through bodies, and the emissivity from their surfaces, and carried out his work to such effect that his results form the basis of modern theory on these subjects.

In 1880, magnesia was adopted in the U.S.A., and cork was experimented with in Germany some few years later, asbestos compositions, hair felts, silicate of cotton, etc., following in due course. Aluminium foil and glass-silk constitute the more modern types of insulation, together with high-temperature compositions having a magnesia base and high-temperature bricks having a diatomaceous base.

Theory of Heat Transfer.

Much work has been carried out in recent years to establish theoretical formulæ for heat losses by conduction, radiation, and convection which will closely approximate to those found in actual practice. It is proposed, therefore, to deal with these briefly in the above order.

Conduction.

For a flat surface the rate of heat flow through a substance can be established from the formula

$$Q = \frac{KA(T_1 - T_2)}{L}$$

where Q = rate of heat flow, K = thermal conductivity of the substance, A = area of surface, T_1 and T_2 = the temperatures on either side of the substance, and L = the thickness of material.

By integration this formula can be adopted also to cylindrical bodies giving the result

$$Q = \frac{K\,.\,(2\pi N)(T_1 - T_2)}{\operatorname{Log}_e \frac{R_2}{R_1}}$$

where N = length of cylinder, and R_1 and R_2 = inside and outside radii.

Radiation.

The heat transferred by radiation between two surfaces depends only on the temperature and nature of the surfaces and can be calculated from

$$H = E(T_1^4 - T_2^4)$$

where H = heat emitted from unit area in unit time, T_1 and T_2 = absolute temperatures of the surfaces emitting and receiving radiation, and E = constant depending on the emissivity (e) of the surface.

Maximum emissivity ($e - 1$) is given by a perfectly dead-black surface and is known as "black-body" radiation, under which condition the value of $E = 17 \times 10^{-10}$ when T_1 and T_2 are given in degrees Fahrenheit.

The above expression can therefore be rewritten as follows:

$$H.(\text{B.T.U.}) = e17 \times 10^{-10}\,(T_1^4 - T_2^4)$$

From the experiments carried out at the N.P.L., Griffiths and Davis established values of e for certain surfaces as follows:

Surface	E
Dead black	1
Black paint and enamel	1
Green " "	1
White " "	1
Aluminium paint	0.7
Sheet copper	0.15

Furthermore, it has been definitely established that a highly polished sheet-metal surface gives the lowest known emissivity.

Convection.

It has been found impossible to establish any simple formula to give accurate results in all circumstances for heat lost by convection, owing to factors, such as atmospheric conditions, varying to a considerable extent. However, under still atmospheric conditions, Griffiths and Davis show that the heat lost by convection can be reasonably approximated by the expression

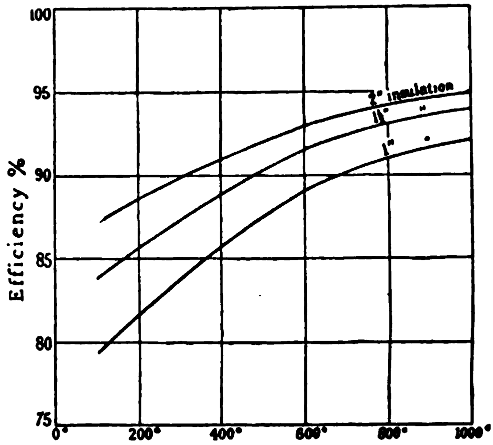
$$H_c = C(T_1 - T_2)^{1 \cdot 25}$$

C being a constant varying according to the size and type of surface in question.

Moreover, it has been established that for cylindrical bodies in a horizontal plane the heat loss per unit area due to convection decreases as the diameter of the cylinder increases up to a maximum of approximately 8 in., and remains practically constant for diameters greater than this, giving a value $C = 0.3$.

Tests of Material.

Unfortunately, no simple instrument or set of instruments exists at the present time which will enable us to calculate the heat lost by any type of insulation under service conditions, for to do this, it will be appreciated that the values of k, e, C, T_1 and T_2 must be established with accuracy. Consequently, it is usually left to the N.P.L. to carry out tests on makers' samples and publish figures which will give to the consumer sufficient information as to the relative values of the various insulating materials. To this end the figures usually given show the thermal efficiency (k) of the material given in B.T.U. per hour per 1-in. thickness of material per 1° F. difference in temperature, and also the saving of heat loss due to the insulation, given as a percentage of the heat loss from the bare pipe and known as the " efficiency " of the insulation.



Temperature of pipe, deg. F.

FIG. 1.

The value of k is obtained by the Hot Plate and Guard Ring Method, whilst the " efficiency " is obtained from a standard length of test-pipe under steam, the heat loss being calculated from the amount of condensate obtained from the pipe under steady conditions, or from an electrically heated pipe, in which case, the heat loss is obtained from the power necessary to maintain steady conditions on the surface of the insulation.

The term " efficiency " is inclined to be applied rather loosely when referred to insulation, as it should always be qualified by the temperature at which the figure was obtained. The graph (Fig. 1) illustrates how " efficiency " varies directly as the temperature of the pipe, and has been drawn up from figures obtained by the N.P.L. when testing samples of 85 per cent. magnesia covering, 1 in., 1½ in., and 2 in. thick.

Results in Practice.

It is not generally realised how great is the loss of heat from an uncovered steam pipe or boiler surface. Table I shows the rates of heat loss per square foot of pipe surface per degree F. difference in temperature pipe to air through a range of temperatures ; also the equivalent rates of heat loss through an efficient insulating material, assuming in each case an air temperature of 70° F.

TABLE I.

Temperature of pipe (degrees F.)	100	200	300	400	600	800	1,000
Loss of heat from bare pipe per sq. ft. per hour per degree F., diff. of temp. pipe to air, B.T.U. ..	1.95	2.27	2.75	3.37	5.06	7.12	9.61
Corresponding heat loss with 1-in. insulation ..	0.40	0.42	0.45	0.48	0.55	0.64	0.75
Corresponding heat loss with 1½-in. insulation ..	0.31	0.33	0.35	0.37	0.43	0.51	0.60
Corresponding heat loss with 2-in. insulation ..	0.25	0.26	0.28	0.30	0.35	0.41	0.49

Applying the figures shown in Table I to a concrete example, we see that the heat loss from 100 sq. ft. of uncovered steam pipe (equivalent to 95 lineal feet of 4-in. O.D. pipe) carrying steam at a pressure of 235 lb. per sq. in. in gauge (corresponding temperature 400° F.) will amount to 111,210 B.T.U. per hour. By the use of an insulating material having an efficiency of 91 per cent. under these conditions, the heat loss can be reduced to a figure of 9,900 B.T.U. per hour, showing a saving of 101,310 B.T.U. per hour.

Extending this figure still farther, and assuming that the steam is obtained from a coal-fired boiler having an efficiency of 70 per cent., working 8 hours a day on 250 days a year and burning coal having a calorific value of 11,500 B.T.U. per lb., we see that the equivalent wastage of fuel will amount to 11¼ tons per year, showing a saving of £8 9s. a year, assuming coal at 15s. per ton. Further examples under similar conditions but with higher initial steam temperatures will afford the following results:

Temperature of steam	600° *F.*	800° *F.*	1,000° *F.*
Bare pipe loss per hour, B.T.U. ..	268,180	519,760	932,170
Insulated pipe loss per hour, B.T.U. ..	18,550	29,930	47,530
Saving due to insulation per hour, B.T.U.	249,630	489,830	884,640
Coal equivalent, tons per annum ..	27.75	54.5	98.25
Saving per annum	£20 16s.	£40 18s.	£73 14s.

When considering the foregoing figures, it should be appreciated that the cost of insulation to obtain these economies would range from approximately £6 to £12, according to the sizes of pipes covered. Thus it will be seen that the initial outlay on the insulation can be recovered on the saving of fuel within a few months of operation of the plant.

Properties of Insulation Materials.

Most insulation materials are placed in direct contact with the surface to be insulated, and are of such a nature that it is necessary to protect their external surfaces from damage or atmospheric conditions. It will be seen, therefore, that heat is passed through the insulation by conduction and is carried away from the external surface by radiation and convection.

It follows that the first essential of any good "insulator" is the possession of a low thermal conductivity together with a low specific heat to avoid wastage of heat during initial warming up. Furthermore, the external covering or protection should be of such a nature that the losses due to radiation and convection are reduced to a minimum. To this end, polished sheet-metal is undoubtedly the most efficient of all external coverings, but owing to the high initial expense of this material, it is more usual to adopt coverings such as canvas and asbestos cloth, well painted, or special hard-setting cement trowelled off to a smooth surface.

It is interesting at this point to note that cases have occurred in the past where the loss of heat after insulation has been greater than that from the bare surface, particularly in the case of small steam pipes covered with 1 in. or more of so-called non-conducting composition, having a high thermal conductivity and a poor external surface whose area per lineal foot will probably be six or eight times greater than that of the pipe.

Modern Practice.

In dealing with the practical application of insulating materials, it is proposed to work through the various temperature ranges and to detail materials in use over each particular range.

50° *F. to* 212° *F.*—It is only at the upper end of this temperature range that insulation becomes of any importance and, in general, no great efficiency is called for, and materials such as hair felt, cork, magnesia, asbestos compositions, slagwool, etc., are usually adopted under these conditions. Low initial cost and reasonable efficiency being the requirements met by these materials.

212° *F. to* 600° *F.*—There is no doubt that this range of temperature calls for the greatest volume of insulation work to-day, including, as it does, steam plant with little or no superheat, hot-air warming and drying systems, etc. It is not surprising, therefore, that the range of insulating materials in this section is very extensive, including asbestos compositions, asbestos rope, compressed asbestos blocks and felts, asbestos fibre or magnesia-filled mattresses, magnesia, slagwool, glass-silk, alfol, diatomaceous compositions, etc.

It is proposed, therefore, to deal with these materials in the above order, and to an extent in accordance with their relative merits or demerits, as the case may be.

Asbestos Compositions.

A title which covers a " multitude of sins." Most insulating contractors have a so-called asbestos composition of their own make, and whilst some of these can lay claims to reasonable efficiencies, there is no doubt that many of them are of poor quality and can claim as their only asset the property of low initial cost.

Asbestos itself has a high density and a relatively high thermal conductivity, and the same may be said of most asbestos compositions, some of which may have densities as high as 40-50 lb. per cu. ft. Cases also have occurred where active corrosion of pipes, etc., has been set up by these materials.

Asbestos Rope, when properly applied, can give reasonably good efficiency, and, due to its high mechanical strength, is usually adopted in cases where it is necessary for the insulation to be stripped at frequent intervals. Improper application, however, can result in very poor efficiencies being achieved, and for this reason, together with the relatively high initial cost, it is not extensively used as an insulating medium.

Asbestos Blocks are comprised of asbestos fibre only, interwoven and bonded in the form of slabs or sections suitable for all sizes of pipes. For highest efficiency the bonding should not be too close, but should be free enough to entrap a reasonable quantity of air between the fibres without excessively reducing the mechanical strength. Among the advantages to be obtained from the use of this material may be mentioned the following : non-inflammability, permanent thermal conductivity, reasonable mechanical strength, ease of application, no deterioration under the action of water, and non-corrosive.

Possible disadvantages comprise : moderately high thermal conductivity, high density, and relatively high initial cost.

Mattresses, made up of an outer covering of asbestos cloth and filled with either asbestos fibre or magnesia, form an excellent protection for such parts as need frequent examination, such as flanges, valves, man-hole and mud-hole doors, economiser tops, etc. When made and fitted correctly, give reasonable efficiency, whilst advantages and disadvantages follow those previously outlined as applying to asbestos blocks.

Magnesia.

This is probably the most widely used of all insulation materials at the present time. It is made up in the form of slabs and sections and also as a powder known as " plastic." In this form it is rendered down with water and applied in layers in the form of a plaster. Composition by weight consists of 85 per cent. hydrated magnesium carbonate ($3MgCO_3Mg(OH)_24H_2O$) with the addition of 15 per cent. asbestos fibre to form a binder.

The plastic form of this material is exceedingly useful in that almost any type or shape of surface may be covered inexpensively, whilst for flat surfaces and pipes the slabs and sections prove equally satisfactory.

Up to about 600° F., at which point disintegration commences, magnesia can be stated to possess almost all the properties and advantages required of an insulating material, viz., density low (11-12 lb. per cu. ft.) ; thermal conductivity low, ranging from 0.41 B.T.U. at 100° F. to 0.564 B.T.U. at 600° F. It is non-corrosive and non-inflammable, and unaffected by the action of water, whilst initial cost is reasonable.

Certain disadvantages may be found in that the magnesia powder tends to be blown about and settle in the form of a white dust when being handled, and, moreover, the mechanical strength of the material is not great. A further advantage may here be noted, however, in that mechanical damage *in situ* may be easily repaired with magnesia in plastic form.

Glass-silk.

Although brought forward some years ago, this has made little headway until comparatively recent times, when manufacture was commenced in this country, and improved methods of application adopted. Application is now made in bulk, or more usually in mattress or strip form. Strips are made up in various widths to suit varying sizes of pipes, and comprise backings of papers or canvas between which the glass-silk is securely sewn. In application to pipe lines the strips should be put on, " puttee " fashion, in two or more layers, with alternate layers wound in opposite directions; canvas or cement may then be used for the external covering.

As the name implies, this material is composed of glass in thread-like form, the thread or fibre being drawn from a molten glass bead. Considerable air is entrapped between the fibres, and this, together with the reflective properties of the highly polished fibres, no doubt account for the low thermal conductivity of 0.21 B.T.U. obtained at 30° F. with a density of 10 lb. per cu. ft. Mechanical strength in the mass is reasonably high, but the weaker fibres tend to break up under handling. Other advantages may be enumerated briefly as follows: non-corrosive, non-hygroscopic, fire-proof and reasonable ease of application.

Disadvantages are: danger to operatives continually handling, unless gloves and masks are worn; liable to consolidate when applied in bulk, with resultant increase in conductivity.

Diatomaceous Compositions.

Diatomite is a siliceous substance of organic origin, being made of the cases of minute plants known as diatoms, which inhabit fresh and salt water and marshy land. The quality of the various deposits, however, varies considerably, and the poorer qualities, which may contain certain impurities liable to attack metals, are not to be recommended. In the pure form, however, this material can be usefully applied as a first layer on high-temperature work, for although the thermal conductivity is relatively high, the mechanical strength is high and density low.

600° F. to 1,000° F.

High-pressure superheated steam plants of modern design, Diesel engine exhausts, oven and furnace sides, etc., are items which fall within this temperature range, and the popular insulating materials in this category are relatively few. Alfol, glass-silk and slagwool, however, are materials which can be adopted as in the lower temperature ranges. High-temperature magnesia compositions in the form of magnesium silicate have been produced and are widely adopted, being capable of withstanding temperatures considerably higher than 1,000° F. The properties of these materials are closely akin to those of magnesia itself, and in practice it is usual to apply only sufficient high-temperature composition to reduce the surface temperature to the region of 600° F., after which the standard grade of magnesia is applied to build up the required thickness of insulation.

1,000° F. and over.

For the higher ranges of temperature such as are found in furnaces, kilns, gas producers, etc., it is useful to break down the first heat from the inside of the furnace by means of high-temperature insulating bricks having a diatomaceous base, and fitted between the firebricks and outer lining of the furnace. These bricks are of low density and have a low thermal conductivity, together with a reasonable degree of mechanical strength. As a means of conserving heat in the furnace such bricks have been found to be exceedingly effective, and when applied to the recommended thickness will give efficiencies of the order of 75-80 per cent.

Tests carried out on two types of brick, A and B, show the following results :

	Type A	*Type B*
Density, lb./cu. ft.	33	41
Crushing stress, lb./sq. in.	170	400
Shrinkage at 1,500° F.	0.12%	—
„ 1,600° F.	0.44%	—
„ 2,000° F.	—	0.10%
Refractory test	2,250° F.	2,615° F.

Thermal Conductivity.

Hot face temp.	*Cold face temp.*	*Type A*	*Type B*
698° F.	86° F.	0.93	1.51
1,157° F.	86° F.	1.10	1.78
1,598° F.	86° F.	1.19	1.99

Figs. 2 and 3 show furnace walls built up of ordinary firebrick and insulating brick with the relative drop in temperature through each layer.

In the case of Fig. 2, the heat loss when constructed as shown, would amount to 288 B.T.U. per sq. ft. per hour, against a loss of 1,100 B.T.U. per sq. ft. per hour from a similar wall made up of firebrick only. The corresponding figures for Fig. 3 would be 364 B.T.U. for the insulated wall against 1,975 B.T.U. for the firebrick wall.

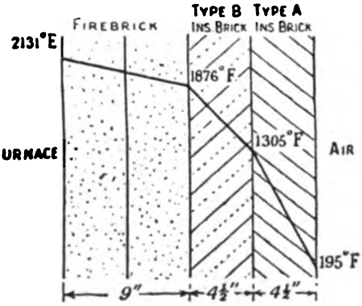


FIG. 2.

Comparisons.

It may be of interest at this point to compare the efficiencies of some of the more important insulating materials. The following Table has been drawn up from the results obtained by the N.P.L. on makers' samples, and may be taken as representing values that could be obtained in practice under ideal conditions. Figures given show the efficiencies obtained from pipe temperatures of 300° and/or 600° F. with a corresponding atmospheric temperature of 70° F.

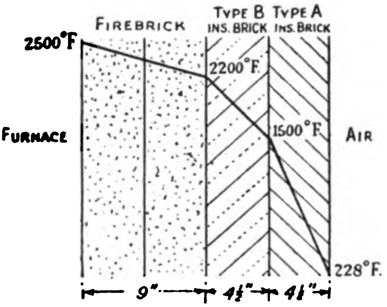


FIG 3.

It is unfortunate that all the above tests were not carried out under identical conditions, particularly as regards external coverings. The figures shown, however, will serve to indicate that, by the choice of a suitable thickness of material and external finish, all the well-known coverings can be fitted to give any reasonable efficiency.

From the consumers' point of view, therefore, the adoption of any form of material *to give a stated efficiency* may be said to depend on the initial cost, durability and appearance of the finished insulation.

It should be appreciated, however, that for every class of work

		Efficiency		
Material	*Thickness*	*Pipe temp.* 300° F.	*Pipe temp.* 600° F.	*External surface*
Alfol ..	.. 2"	—	94%	Not known, probably sheet-metal.
Glass-silk	.. 1.5"	90%	91.5%	Canvas.
Magnesia	.. 2"	89.5%	93%	Smooth natural finish.
,,	.. 1"	83.5%	89%	
Slagwool	.. 2"	91.5%	—	Sheet-metal.
,,	.. 1"	85%	—	

there is an " economic thickness " of insulation, which correlates the cost and the purpose of the installation. For example, in a steam-pipe system made up of varying sizes of pipes, the smaller pipes need not carry the same thickness of insulation as the larger pipes, owing to their relatively smaller surface area and consequent lesser radiation.

BUILDING RESEARCH STATION, GARSTON, NR. WATFORD, HERTS.

THE MEASUREMENT OF EQUIVALENT TEMPERATURE

By A. F. DUFTON, M.A., D.I.C.

THE joint Committee of the Medical Research Council and the Department of Scientific and Industrial Research, which was set up to review the physical criteria, physiological conditions and nomenclature involved in heating and ventilation research and to examine the possibility of adopting standard terminologies and methods of measurement, emphasised that it is important to have an instrumental method for measuring heating and ventilation effects which will allow properly for the various physical factors influencing human comfort.

The Committee found that for ordinary conditions of artificial heating, where humidity effects are negligible and ventilation does not vary between wide limits, the eupatheoscope will give reliable records and may be regarded as a standard instrument.

It may be remarked here that the eupatheoscope is a physical instrument designed to measure and record a quantity analagous to the physiological sensation induced by a cool environment. The instrument[1] is essentially a black-painted cylinder at 75° F., the loss of heat from which is recorded and scaled in degrees of *equivalent temperature*, the equivalent temperature of an environment being defined as that temperature of a uniform enclosure in which, in still air, a sizable black body at 75° F. would lose heat at the same rate as in the environment.

---

[1] *The Equivalent Temperature of a Room and its Measurement.* Building Research Tech. Paper No. 13, 1932, H.M.S.O., 6d. net.

The need has now been felt for a simpler instrument for general use, the eupatheoscope, which was designed purely as a research instrument, being somewhat cumbrous and expensive. The Committee, in its interim report, a summary of which was published in the Report of the Building Research Board for the year 1931, suggested that some instrument might be used to give a correction factor, for radiation effects, of readings taken with the kata-thermometer of the cooling power of an environment and that, in spite of the complication, this aspect merited further development. The Committee recommended that eupatheoscope readings should be taken as a basis for comparison of readings taken with such combinations of instruments.

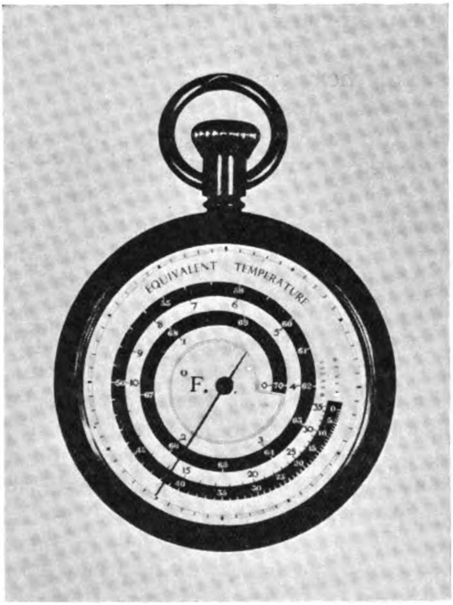


FIG. 1.

A correction factor for the excessive convection loss of a kata-thermometer can be achieved by the use of a second kata-thermometer with a surface of different emissivity and an account of the testing of pairs of such thermometers has been communicated to the *Journal of Hygiene.*[2] One pair comprised alcohol-in-glass thermometers with bulbs 2 in. long and ¾ in. in diameter, one being blackened and the other silvered. The thermometers had a cooling range from 75½° to 74½° F. and were tested in environments chosen with a view to the inclusion of extreme conditions. The probable error of a determination was found to be only ¾° F. Since the equivalent temperature is essentially determined as a cooling power extrapolated from those of the two kata-thermometers, this was regarded as highly satisfactory.

The silvered thermometer was found to cool more slowly than was really convenient and further experiments have now been made with another pair of thermometers: the range of cooling of the silvered instrument was made less than that of the black thermometer, and, for the sake of durability, the surface of the black instrument was of glass, unpainted. This pair of thermometers has been compared with a eupatheoscope under conditions somewhat more precise than those which obtained in the previous tests.[3] The probable error of a determination of equivalent temperature, the mean of three pairs of readings, was found to be little more than ½° F.

The equivalent temperature was computed in degrees Fahrenheit as $75 - 1350/B + 675/S$ from the cooling times in seconds, B and S, of the two thermometers. In order to simplify this computation a special face has been fitted to an ordinary stop-watch, Fig, 1, which enables the equivalent temperature to be evaluated by the mere addition of two numbers. The number corresponding to the cooling of the silvered thermometer is added to that corresponding to the cooling of the black thermometer, and the sum gives the equivalent temperature in degrees Fahrenheit. Thus, the watch shows 35 when the black thermometer cools in 30 seconds and 20 if the silver thermometer cools in 27 seconds; whence the equivalent temperature is $35 + 20 = 55°$ F.

Arrangements are being made for the instruments—a pair of thermometers and a stop-watch—to be marketed under the name of *eupatheometers* by Messrs. J. J. Hicks of Hatton Garden.

---

[2] *Journal of Hygiene* 1933, *33*, (3), 349 and (4), 474.

[3] A survey of the wind tunnel in which the previous work was done showed a considerable variation of air-velocity at different points. I am indebted to my colleague Mr. W. G. Marley for pointing this out and for his valued assistance in the work.

SYLLABUS OF
(1) GRADUATES' EXAMINATION
(2) ASSOCIATE MEMBERS' EXAMINATION

REVISED 1934

The knowledge required by a Graduate candidate will be such as may be expected from an intelligent student, who in addition to having had practical experience, has acquired a moderate knowledge of elementary practical mathematics, machine construction and drawing, mechanics (solids and fluids), elementary science (heat and electricity), and the elementary principles of heating, ventilation and hot-water supplies under Sections 2 and 3 of the Schedule.

For the Associate Members' examination a more advanced knowledge of each of the subjects is necessary, and a candidate must pass in Section 1 together with any two of Sections 2, 3, and 4.

Examinations : For Graduate candidates a three hours' paper will be set in two parts, part 1 containing questions on Section 1 of the Schedule and part 2 containing questions on Sections 2 and 3 of the Schedule.

For Associate Member candidates, two papers will be set, each of three hours' duration. The first paper will contain more advanced questions on Section 1 and the second paper will contain questions on each of Sections 2, 3 and 4 of the Schedule.

Drawings and Sketches : Candidates will require to be able to make simple, clear and workmanlike sketches of pipe arrangements, fittings, etc., and intelligible sketches showing the general construction and practical details.

NOTES.—There are two grades for the Graduates and Associate Members' Sections—Pass and Honours—the examination being the same for each grade. The Honours students are those who reach a very high standard and satisfy the examiners that their knowledge of the profession is above the average. Should a candidate, who has obtained a Pass in the Associate Members' grade desire to sit again with a view to obtaining Honours, he may do so.

SCHEDULE

Section I

ARITHMETIC.—Addition, subtraction, multiplication and division of fractions. Conversion of fractions to decimal quantities. Addition, subtraction, multiplication and division of decimal quantities. Square root. Power of numbers. Ratio and proportion. Averages. Simple interest. Percentages.

PRACTICAL MATHEMATICS.—Use of symbols. Substitution. Simple equations. Addition, subtraction, multiplication and division of algebraic quantities. Mensuration. Rules for areas and volumes of simple figures and solids. Indices and index notation. Use of formulæ and their construction from data. Simultaneous equations. Use of logarithms. Graphs. Plotting of observed relations between two variables. Determination of laws. Trigonometrical functions. Sine, cosine and tangent. Use of slide rule.

GEOMETRY.—Setting out and measurement of angles. Use of scales. Plans, elevations and sections. Intelligible freehand sketches of constructional details. Properties of the triangle and the circle. Projections of simple solids in simple positions. Isometric and planometric drawing.

The use of squared paper in plotting simple expressions. Practice in the writing of correct English, with a view to preparing *job reports*, should have been acquired.

MECHANICS.—Matter : States and properties of matter, mass, gravitation and weight. Units of mass and weight. Laws of motion. Speed, velocity and acceleration. Force. Friction. Work, unit of work. Power, horsepower. Energy—kinetic and potential. Centrifugal force. Moment of a force, illustrating centre of gravity, levers, simple machines, e.g., wheel and axle, pulley-blocks, screw-jacks, etc. Laws of equilibrium of bodies at rest. Mechanical advantage and velocity ratio of simple machines. Properties of materials.

HYDROSTATICS.—Properties of liquids, pressure in pipes and cylinders. Specific gravity. Elementary principles of flow of water through pipes, mean velocity, discharge and head. Friction through pipes, cocks, valves, etc. Bernoulli's law. Venturi meter. Hydraulic gradient, discharge of orifice and weirs.

PNEUMATICS.—Properties of gases and vapours. Pressure of atmosphere. Pressure gauges, pumps and syphon. The principle of the Barometer.

PHYSICS.—Heat. Nature of heat. Specific heat, latent heat, sensible heat. Temperature and humidity. Quantity of heat. Distinction between temperature and quantity of heat. Units of heat. Calorie, British Thermal Unit (B.T.U.). Thermometric scales, conversion from Centigrade to Fahrenheit degrees, etc. Types of thermometers and pyrometers. Kata-thermometers, Eupatheoscope and their application. Specific heat. Transmission of heat, conduction, convection, radiation. Properties of steam. Expansion of solids, linear, cubical. Expansion of liquids and gases, Boyle's law, Charles' law. Non-conductors and their use. Elementary principles of refrigeration and refrigerants. Sound, electricity and magnetism. Simple properties of magnets. Electrical units—volt, ampere, ohm, watt. Ohm's law. Measurement of units. Heating effects of currents. Voltage, current and power in direct, single-phase, 2-phase, 3-phase systems.

CHEMISTRY.—Chemical nomenclature ; atomic weights ; electrolysis ; gases and solids in solution. Water—chemical composition of water ; chemical composition of impurities ; hardness, permanent and temporary ; softening processes and chemical re-actions involved. Testing and analysis of water. Nature of combustion. Chemical composition of fuels—solid, liquid and gaseous. Products of combustion. Air required for combustion including estimation from ultimate analysis. Carbon monoxide and carbon dioxide. Products of sulphur and their effects on metals. Oxidation.

Section 2

HEATING.—Loss of heat from buildings. Calculation of heat losses and rules. Methods of heating, open fires, stoves, hot water, gas, electric and steam apparatus. Comfort effect. Systems—steam and hot water, low pressure and high pressure, one and two pipe accelerated. Low temperature and high temperature radiant heating systems. Pipe sizing. Radiators—construction, emission, heating surface of all types of radiators and coils. Boilers—low pressure, high pressure, wrought-iron or steel, cast-iron sectional, and their fittings. Calorifiers and other water-heating devices. Electric storage heating system. Electric boilers and water heaters. Gas boilers and water heaters. Automatic temperature control. Oil-firing apparatus. Automatic stokers. Steam traps, reducing valves, vacuum pumps and control valves for steam, water, gas and air. Pressure gauges, water-level indicators and their connections. Boiler feeders, injectors, pumps, etc. Feed water, expansion and feed-water regulating tanks and fittings. Chimneys, proportion and height. Insulation, types and efficiencies.

HOT WATER SUPPLY.—Systems and arrangements. Types and sizes of boilers. Storage tanks, cylinders, calorifiers and their mountings. Pipe sizing and cold feeds. Causes and effect of corrosion and deposit, and remedies. Circulation of water in pipes and boilers and materials for use with various waters. Insulation, types and efficiencies.

PIPES AND FITTINGS.—Methods of connecting cast-iron, wrought-iron, steel, brass and copper pipes for steam, water, gas, oil and air distribution. Contrivances adopted to provide for expansion, contraction and flexibility of pipe-lines. General proportions and construction of tee and branch pieces, riser connections, general and special fittings of cast, wrought and malleable iron, gunmetal, etc.

WORKING TOOLS.—Hand and power tools required for bending, cutting, setting, screwing, flanging, jointing, welding, etc., pipes and fittings.

Section 3

VENTILATION.—Properties and movement of air. Humidity and measurement. Requirements of ventilation. Comfort effect. Air inlet and outlet registers, operation and regulation. Ducts, valves, dampers, etc. Systems—plenum, exhaust and gravity. Distribution of air, size and form of main and branch ducts. Position of inlet and outlets, and sizes for various conditions of pressure and temperature. Measurement of velocity of air through ducts. Anemometers, pitot tubes and manometers. Friction of ducts, bends, tees, etc. Design of combined systems of heating and ventilation, including unit heaters. Air heaters using steam, hot water, electricity and gas. Air-conditioning apparatus including washing and filtering, dehumidifying and dehumidifying appliances and their control. Fans and blowers. Fan drives—direct-coupled and belt drives. Characteristics and application of various commercial types of motors. Application of refrigeration to air conditioning. Insulation types and efficiencies. Sound and vibration reduction devices.

Section 4

CENTRAL STATION LAYOUT AND EQUIPMENT.—Location of boiler-house. Access and ventilation. Fuel space. Flues and chimneys. Types of steam boilers ; features of Cornish, Lancashire, water-tube, Economic return flue, vertical and other boilers ; boiler mountings ; mechanical stokers ; fuel and ash handling plant ; boiler circulators ; blow-down arrangements ; priming in steam boilers ; induced, forced and natural draught ; economisers ; oil-firing apparatus ; smoke prevention ; oil and water separators ; steam traps ; reducing valves, feed-pumps, injectors, etc. ; arrangements for expansion of piping ; accelerators ; turbines and electrical drives ; tanks for condensate ; feed-water measurement and treatment ; boiler efficiency and heat balance. Layout of steam piping and central station equipment generally. Recording and indicating instruments. Boiler-house routine and records.

SUGGESTED TEXTBOOKS

HEATING AND VENTILATING ENGINEERING (SECTIONS 2, 3 and 4).

No textbooks are prescribed for the examinations, but the following list of works is given for the guidance of students in selecting books for study and reference. The student is recommended, if possible to examine books before purchase, in order to ensure that they are suitable for his individual purpose. The majority of these may be available in Public Libraries, or may be obtained on request by Library Authorities.

" Heating and Ventilation." By Rietschel and Brabbèe. McGraw-Hill Publishing Co. 1927. 27s.

" Heating, Ventilating and Air Conditioning." By Harding and Willard. J. Wiley & Sons, New York ; and Chapman & Hall, London. 1932. 62s. 6d.

" Heating and Ventilating." By L. J. Overton. Sutherland Publishing Co. 12s.

" Ventilation : A Textbook for Students and Engineers." By E. L. Joselin. Arnold. 1934. 16s.

" Engineering Equipment of Buildings." By A. C. Pallot, B.Sc., Wh.Ex. Sir Isaac Pitman & Sons, Ltd. 1932. 15s.

Also

" Practical Treatise on Heat." By Thomas Box. Spon. O.P.

" Theory and Practice of Heating and Ventilation." " Barker on on Heating." By A. H. Barker. Carton Press. 1912. 25s.

" Hydraulics." By F. C. Lea. Arnold. 4th Ed. reprinted 1926. 18s.

" Hydraulics." By A. H. Gibson. Constable. 3rd Ed. 1925. 24s.

" Practical Hydraulics." By Thomas Box. Spon. 17th Ed. 1928. 6s.

" Warming Buildings by Hot Water." By F. W. Dye. Spon. 12s.

" Hot Water Supply." By F. W. Dye. Spon. 7th Ed. 1925. 6s.

" Steam Heating." By F. W. Dye. Spon. Reprinted 1934. 8s. 6d.

" Domestic Electric Heating." By H. G. Solomon, M.I.E.E. Crosby Lockwood. 1927. 3s. 6d.

" The Principles of Heating and Ventilation." By Dr. H. M. Vernon, M.A., M.D. Arnold. 1934. 14s.

" Domestic Utilisation of Gas." By Le Fevre & Smith. Walter King, Ltd. 1932. 5s. 6d.

" Scientific Domestic Appliances." By C. R. Darling. Spon. 1932. 5s.

ABSTRACTS

Heating Aquariums. 727.59

Heating of aquariums offers some special problems. Accurate control of the temperature is particularly important here as many tropical fish cannot stand temperature variations.

In many cases the tanks are not directly heated but obtain their heat from the room. This is an inexpensive and convenient method when there are a number of tanks in the room and when the temperature of the room is not lowered during the night. If the tanks are large, 50 gal. or over, room temperature drops will not affect the water greatly if the tanks are covered. If the drop is large or over long periods of time, some special means of heating must be provided.

The best method is by means of a thermostatically-controlled electric immersion heater. With one of these the temperature can be held within 1° of the required point. A rule for determining the size of the heaters is to allow 2½ watts per gal. for each 10° of maximum temperature difference. Thus, a 15-gal. tank kept at a temperature of 80° in a room where the drop may be to 60° would require a heater of 75 watts.

Unless the tank is continuously aerated, the heater should not get hot enough to form bubbles as this drives the air out of the water. Also, in order to get the proper heat distribution, the heater should be located near the bottom of the tank. If it is kept at the top no convection currents will be set up and the lower portion of the water will not receive any heat. (*Heating and Ventilating*, June 1934.)

Boilers for Oil-Burning. 621.183.57

The flame must be so adjusted at oil and air mixture that practically complete and therefore economical combustion will be the result. It is not necessary to go into a study of the theory of combustion further than to know that about 200 cu. ft. of air are required for the complete combustion of 1 pound of oil, and that approximately 20 per cent. or more, of excess air is usually required per pound of oil in actual operation. This means a total of about 250 cu. ft. of air for the burner per pound of oil burned, depending on the burner.

It is not so necessary to know the exact volume of air required as it is to know how to adjust the oil and air mixture at the burner in order to secure a good flame of the correct shape for the combustion chamber and of the correct size and intensity to furnish the necessary amount of heat without smoke or too much excess air. Manufacturer's instructions should be followed.

Flame intensity or temperature is important. A reasonably close indication of the flame temperature is given by its colour.

Deep orange is about 2,000° F., a white flame about 2,400°, bright white about 2,550° and dazzling white about 2,740°. These temperatures do not relate to blue flame burners.

Combustion space must be ample for the flame. Manufacturers of modern oil burning boilers see to this in the design and construction of their boilers. Most coal burning boilers have a large enough combustion chamber to permit easy conversion to oil burning. Care should be taken that the boiler, smoke pipe and chimney are tight against gases of combustion being blown into the building for the fan blast, particularly when starting up with a cold chimney. (T. N. Thomson. *Plumbing and Heating Trade Journal*, May 1934.)

Copper and Drinking Water. 613.31

Some few towns appear from their regulations to be suspicious of copper as a conveyance of drinking water. Facts have proved in most instances that there is no justification for this assumption either in the nature of the water supplied or in other local circumstances.

Such objections have mostly arisen from a lack of experience of the material or from the assumption that the known objections to wrought iron probably apply to copper. There have been known definite cases of water passing through copper from private supplies, where the surface water was taken from moorland for drinking purposes and, in certain cases, from wells. In these instances there was a very strong acid re-action with the copper.

In cases of this description where water has a very acid content, copper should not be used ; even so, lead pipe under these circumstances would be even more dangerous than copper. The final answer to objections to copper lies in the fact that extensive enquiries have not revealed a single example of any one being harmed through drinking water conveyed by its means.

The results obtained from an extensive series of tests planned to ascertain the reactions on copper of the actual drinking waters of this country have been most interesting. It has been proved that waters which act upon other metals usually act slightly upon copper taking minute quantities into solution, but any water takes up less copper than it would under similar conditions of lead and, inferentially, much less than that of iron.

It has been definitely proved more copper can be taken up without harmful effects than lead, since copper is not poisonous like lead, and does not accumulate in the system like lead.

In drinking water, 14 parts per 100,000 of copper is found to be quite free from any suspicion of danger. Investigations have shown that water which had not taken up in 24 hours more than the figures stated, was absolutely safe. Copper is less soluble in water than either lead or iron. In copper, which is a more innocuous metal, there is double safety. Acid waters, normally treated for acidity, are equally safe with this metal. Water supposed to be unsafe with copper could not be considered safe with lead. On the other hand, should iron be used under these circumstances, excessive rusting would occur. (W. L. Kilburn, *The Plumber*, June 1st, 1934.)

Infiltration and Heat Loss. 697

I found it impossible to keep a certain home warm and decided to find out the cause. The following information is the result of my "research," gained from the 1932 edition of the A.S.H.V.E. Guide.

A ten-mile wind velocity, which is a safe average except in extreme conditions, will cause 84.9 cu. ft. of air to flow through a crack $\frac{1}{16}$ to $\frac{7}{64}$ of an inch wide, and 1 ft. long, in 1 hour. The heat loss for this is 1.53 B.T.U. for one degree per hour.

The following gives desirable information on other velocities :—

HEAT LOSS AND FLOW OF INFILTRATION FOR ONE LINEAR FOOT $\frac{1}{16}$ INCH TO $\frac{7}{64}$ INCH WIDE FOR ONE HOUR.

Velocity Wind.	*Cubic Feet Infiltration.*	*Heat Loss in B.T.U. per degree.*
5.0	39.3	0.70
7.5	62.8	1.13
10.0	84.9	1.53
15.0	124.0	2.24
20.0	161.0	2.94

The average door or window has about 21 ft. of lineal crack. If the difference between the inside and outside temperature is 82°, 1.53 × 82 × 21 equals 2,634.66 B.T.U. loss. This is equivalent to approximately 11 sq. ft. of steam radiation. (H. G. Brenner, *Domestic Engineering*, May 1934.)

ARBITRATION

Members at one time or another during the course of their business experience find the desirability of being acquainted with the Law of Arbitration, and the recent amendments may possibly be of interest.

The new Act, which will come into force on 1st January, 1935, is to be known as "The Arbitration Act, 1934." It is an amending Act; that is to say, it amends the principal Act of 1889, and the law of arbitration generally, and there are other and additional provisions which will prove of far-reaching importance to arbitrators and disputants.

Any Members who may be interested, can obtain a copy from His Majesty's Stationery Office, Kingsway, W.C.2, price 3d.

HEATING AND VENTILATING INDEX

Heat Emission. 613

Research Sets New Values for Heat Emission from Human Beings. 1 p., 1 illus. Dealing with recent research results in relation to earlier tests : *Heating and Ventilating*, May 1934.

Fans. 622.416.1

Total and Static Pressures and Efficiencies of Fans. A. A. Berestneff. 3½ pp., 5 illus. Dealing with misconceptions of use of the terms total and static pressures : *Heating and Ventilating*, May 1934.

Automatic Control. 697.97

Home Temperature Control Problems. L. M. Parsons and Nelson B. Delavan. 5½ pp., 7 illus. Study of various factors affecting temperature control for maximum winter comfort : *Plumbing and Heating Trade Journal*, May 1934.

Heating. 697

Radiation. Leslie Rayner. 2¼ pp., 1 illus. Dealing with calculation of panel surface calculation, emission of pipes and heat cabinets : *The Plumber*, June 1st, 1934.

Chimneys. 697.8

How High, How Wide, and How Deep Should We Make the Chimney? 3 pp., 3 illus. Discussing chimney draught, draught in boilers and sizing for chimneys : *Domestic Engineering*, May 1934.

Domestic Supply. 696

Sell Water Heating with Close Estimates. B. L. Mathews. 3 pp., 1 illus. Describing how to correctly size gas-fired hot-water storage system, with tables : *Domestic Engineering*, May 1934.

Noise. 534

What is Noise—How is it Measured? W. O. Osborn. 1½ pp., 1 illus. Dealing with noise and how to reduce the subject to a common basis : *Domestic Engineering*, May 1934.

Boiler Explosions. 621.194.7

Misconceptions in Regard to Heating-Boiler Explosions. Edward Ingham. 2¼ pp. Dealing with reasons for boiler explosions : *Heating and Ventilating Engineer*, May 1934.

Drying. 634.9

Principles of Drying. C. W. Ulett. 5 pp., 6 illus. Dealing with table of properties of air and aqueous vapour and design of drying systems : *Heating and Ventilating Engineer*, May 1934.

Fuels. 697

Methods of Firing for Heating and Hot Water Supply Boilers. Louis J. Overton. 2½ pp. Discussing method of arriving at comparative costs of heating systems : *Heating and Ventilating Engineer*, May 1934.

Ventilation. 622.46

Ventilation Testing Instruments and Their Uses. A. T. Henly. 2¾ pp., 2 illus. Dealing with the Hill synthetic air chart and its use : *Heating and Ventilating Engineer*, May 1934.

Insulation. 621.319.37

Asbestos Reinforced Aluminium Foil for Insulation. 5 pp., 4 illus. Describing experiments on metallic surfaces as an insulating medium : *Heating and Ventilating Engineer*, May 1934.

Ventilation. 697.9

Students' Text Book of Heating and Ventilation. Norman Wignall. 4 pp., 11 illus. Dealing with exhaust systems, unit heaters and plenum systems : *Heating and Ventilating Engineer*, May 1934.

Oil Fuel. 621.182.23

Facts that Make Oil-Burning Boiler Selling Easier. T. N. Thomson. 2¾ pp., 8 illus. Dealing with flame, combustion space and other details of construction and operation that make for a better understanding of units : *Plumbing and Heating Trade Journal*, May 1934.

Boilers. 621.193

Steam Boilers : Their Care, Maintenance and Efficiency. William Lambie. 3 pp. Dealing with care of new boilers, pitting and corrosion, feed-water treatment, fuel, efficiency and fuel economy : *Baths and Bath Engineering*, May 1934.

Heating. 697.4

Chauffage par Rayonnement—Application aux Planchers Chauffants. Jacques Mossé. 7½ pp., 5 illus. Dealing with radiant floor heating, emission, advantages and disadvantages of ceiling, vertical and floor panel heating : *Chauffage-Ventilation*, May 1934.

Heat Losses. 536.2

A Time-Saving Method for Figuring Heat Loss. E. A. Bailey. 4 pp., 2 illus. Describing method of determining size of heating equipment for small buildings without measuring each room in detail : *Heating and Ventilating*, June 1934.

THE MEASUREMENT OF AIR VELOCITIES BY MEANS OF SILVERED KATA-THERMOMETERS

By T. BEDFORD, Ph.D. and C. G. WARNER, B.Sc.
Investigators to the Industrial Health Research Board.

COMMUNICATED.

In a recent article in this Journal, Mr. A. F. Dufton[1] has put forward a new type of nomogram for the calculation of air velocities from kata-thermometer readings. This nomogram is applicable to readings of the ordinary body-temperature kata-thermometer with its bulb of polished glass.

The air velocity equation for the kata-thermometer was determined under conditions in which the air and walls were at the same temperature; and under such conditions the equation used by Mr. Dufton gives accurate results. The glass surface of the kata-thermometer bulb has an emissivity of about 0.9, and it follows that if the air and the surrounding surfaces are at different temperatures the radiation effect will cause some error in the estimates of air velocity.

To overcome this difficulty we have used kata-thermometers with silvered bulbs. By means of these instruments air velocities can be estimated with but a very small error, even in the presence of fairly intense radiation. The results of our investigation have been fully described elsewhere,[2] and in this article it is only proposed to refer to the use of silvered kata-thermometers for the measurement of air velocities.

The Kata Factor.

The cooling power (H) of the ordinary kata-thermometer (or (H_S) of the silvered kata-thermometer) is calculated from the equation

$$H = \frac{F}{T} \quad \ldots\ldots\ldots\ldots \quad \text{(i)}$$

where T is the number of seconds taken in cooling through the range 5°, and F is the factor of the instrument.

The factor (F) is determined from observations made in a still air chamber. We have shown that for the silvered kata-thermometer the factor can be calculated from

---

[1] Dufton, A. F. (1934): The kata-thermometer as Leslie's anemometer and a simplified method for computing. *This Journal*, Vol. 2, p. 123.

[2] Bedford, T. and Warner, C. G. (1933): The influence of radiant heat and air movement on the cooling of the kata-thermometer. *Journ. Hygiene*, Vol. 33, p. 330.

$$F = 0.055T\,(97.7 - t)^{1.145} \quad . \; . \; . \; . \; . \; . \; . \quad \text{(ii)}$$

where T is the time taken by the kata in cooling from 100° to 95° and t is the temperature of the air in °F.

The Measurement of Air Velocities.

An equation relating air velocity, air temperature and cooling power was determined from observations made by the whirling

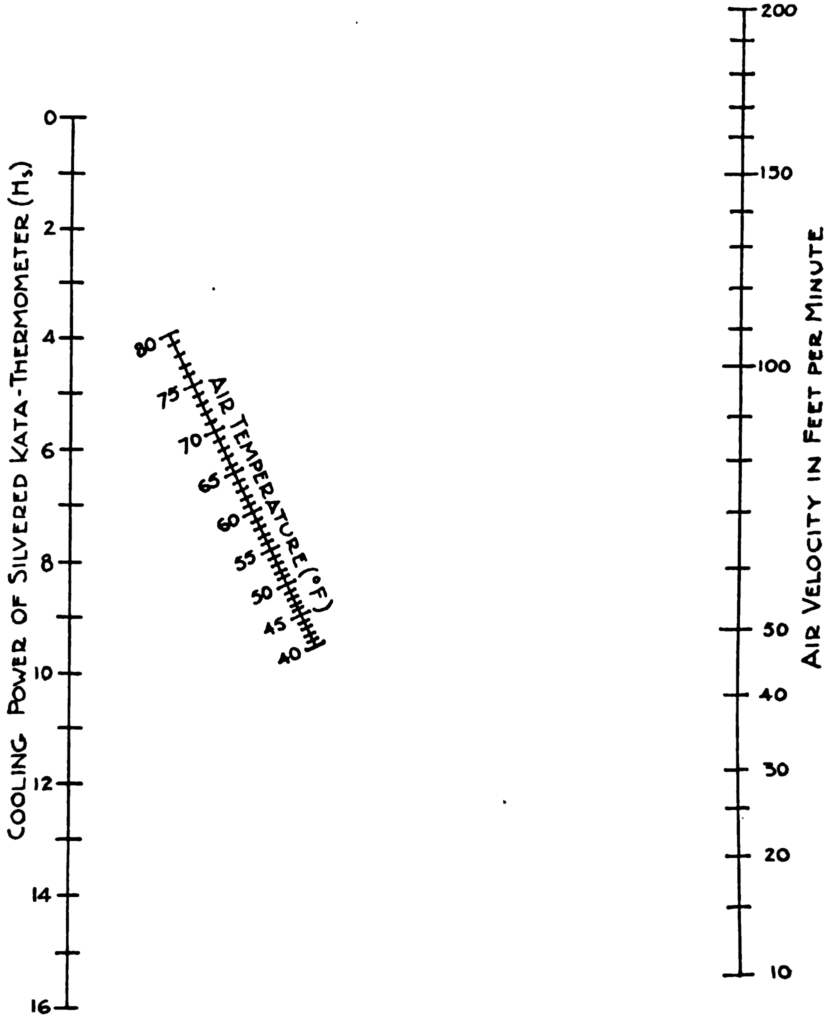


Fig. 1. Chart for the Determination of Air Velocities from Readings of the Silvered Kata-Thermometer.

arm method, a correction being made for swirl effects. The range of velocity covered in these observations was from 10 to 200 ft. per minute, a range which includes any velocities likely to be met with under ordinary conditions of ventilation. Over this range the observations were fitted by the equation

$$H_S = (97.7 - t)\,(0.056 + 0.01584\sqrt{v}) \quad . \quad . \quad . \quad \text{(iii)}$$

where t is the air temperature in °F., and v is the air velocity in feet per minute. Values calculated from this equation are given in Table I.

TABLE I.

RELATION OF AIR VELOCITY TO $H_S/(97.7 - t)$.

$H_S/(97.7 - t)$	v	$H_S/(97.7 - t)$	v
0.11	12	0.20	83
0.12	16	0.21	94
0.13	22	0.22	107
0.14	28	0.23	121
0.15	35	0.24	135
0.16	43	0.25	150
0.17	52	0.26	166
0.18	61	0.27	182
0.19	71	0.28	200

A simpler method of ascertaining the air velocity is by means of the nomogram given in Fig. 1. When a line drawn through the appropriate points on the cooling power (H_S) and temperature scales is produced to cut the air velocity scale, the velocity is at once read off. It has not been thought desirable to complicate the nomogram by including provision for calculating H_S from the cooling time and the kata factor. This calculation only necessitates a simple division which is readily performed on the slide-rule.

The Influence of Radiant Heat on Velocity Determinations.

Reference has been made to the errors which may arise in the calculation of air velocities from observations with the ordinary kata-thermometer if the kata is exposed to radiation from a surface at a temperature differing markedly from that of the air. From the data given in our previous paper it is possible to calculate the magnitude of these errors, but we also performed experiments which bring out this point. A blackened copper bath with a vertical face 12 in. square was filled with boiling water, and the water maintained at boiling point by a carefully screened gas flame. Observations were made with the bulb of the kata-thermometer 10 in. or 7½ in. distant from the centre of the vertical face of the bath, while the stream of air from an electric fan was directed over the bulb of the kata in a direction parallel with the face of the bath. Readings were taken with (*a*) an ordinary kata-thermometer, and (*b*) a kata-thermometer with its bulb silvered.

As an example may be given the results of an experiment in which the kata-thermometer was placed at a distance of 7½ in. from the hot copper surface. The air velocity estimated with the silvered kata-thermometer was 126 ft. per minute, the ordinary kata yielded an estimate of 76 ft. per minute, while it can be calculated that the true air velocity was 130 ft. per minute. The error of estimation from the silvered kata readings was thus only 3 per cent., but with the ordinary kata the velocity was under-estimated by nearly 40 per cent.

The High-Temperature Kata-Thermometer.

In a warm environment the slow cooling of the body-temperature kata-thermometer may make observations somewhat tedious. Results may be obtained more quickly by using the high-temperature kata-thermometer which has a cooling range of 130° to 125° F.

The factor of the silvered high-temperature kata may be obtained from observations in a still air chamber by means of the equation

$$F = 0.0543\, T \cdot (127.5 - t)^{1.127} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(iv)}$$

where T is the number of seconds taken by the kata in cooling from 130° to 125° F., and t is the air temperature in °F. The air velocity equation for this instrument is

$$H_{81} = (127.5 - t)\ (0.0606 + 0.0139\sqrt{v}) \quad . \quad . \quad \text{(v)}$$

where t is the air temperature in °F., and v is the air velocity in feet per minute.

NEW COMMITTEE.

A Joint Committee on " Minimum Specifications for Heating and Ventilating Materials " has been appointed consisting of:

J. W. Cooling, Chairman.
Frank Biggin.
R. C. Ching.
G. L. Copping.
F. H. Horton.
J. L. Musgrave.

RADIANT HEAT AND COMFORT

By HAROLD HARTLEY, D.Sc.*

PAPER READ BEFORE THE INSTITUTE OF FUEL,
MANCHESTER, MARCH, 20th, 1934

In this country it is necessary, for the greater part of the year, to provide in the home an artificial source of warmth to enable comfort to be attained. The temperature at the surface of the body, although somewhat below that of blood heat, is considerably higher than that of the air in our rooms or of the walls of the rooms. A person at rest or in a sedentary occupation loses about 450 B.T.U. per hour; of this, some 43 per cent. is dissipated by radiation, 30 per cent. by convection, and 20 per cent. by water evaporation, the remaining energy being used in the warming of inspired air and food, and in the performance of work.

The loss of heat from the body can be reduced by raising the temperature of the air. This can be done to such an extent that it is no longer necessary for comfort to provide any additional source of heat.

There are, however, objections to such a means of attaining comfort, principally owing to the fact that our bodies are very sensitive to changes in the air temperature when the interchange of heat is effected only by convection. In addition, as the air has to be breathed, the possible effect of the heated air on the respiratory passages has to be borne in mind. Determinations have been made of the temperature conditions required to ensure comfort in a stagnant or an almost stagnant atmosphere. It will be realised that the temperature conditions which apply for still air may not produce the desired result if there is considerable air movement. As some 20 per cent. of the total heat loss is represented by the latent heat of evaporation of water vapour given off from the body, it is to be expected that the humidity of the atmosphere may also influence the sensations experienced. Some work has been published in the United States on the effect of change of humidity on the air temperature requisite for comfort, but it does not seem possible, however, to state definitely what is the precise effect of a given change in the humidity of the atmosphere, or even of a given change in the partial pressure of the water vapour present. In general it can be said that if the air of a room is somewhat hotter than is required for comfort, then increase in the humidity will make the conditions still less comfortable. On the other hand, if the air is too cool for comfort, increase in humidity will tend to increase the degree of comfort. In each case, of course, decrease in humidity would have a converse effect.

---

* Head of the Research Department, Radiation Limited.

Fishenden and Willgress* have shown that with air at 65° F. and the surrounding walls at the same temperature, comfort is attained by a person at rest in the absence of any additional source of radiation. A relatively small change in air temperature, however, upsets the equilibrium condition necessary for comfort. For example, the same authors state that if the temperature of the environment was at 62° F. and there was no additional radiation, the room was found too chilly for continued quiescence, whilst at 68° F. it had become slightly too warm. Further, if the walls are slightly cooler than the air, the latter must be at a temperature above 65° F. to satisfy the requirements of sedentary workers ; an air temperature of 66° F. being necessary in conjunction with solid surroundings at 63° F. or an air temperature of 67° F. with the walls at 61° F. They make the interesting observation : "When the walls and floor were more than a degree or two colder than the air, however, very undesirable conditions prevailed, and chilliness combined with stuffiness was felt when the air temperature was slightly too low for warmth." When the temperature of the walls is a few degrees in excess of the air temperature, however, comfortable conditions are produced.

If there is available a source of high-temperature radiant energy, comfort can be attained with much cooler air. The additional radiant energy necessary is determined by the difference between the temperature of the cooler air and 65° F. For example, the same authors found that with air at 60° F. a mean horizontal component of radiant energy of about 30 B.T.U. per sq. ft. per hour produced warmth, whilst at 55° F. 75 B.T.U. per sq. ft. per hour, and at 50° F. 120 B.T.U. per sq. ft. per hour were required. With air at 45° F. there was required 170 B.T.U. per sq. ft. per hour in the form of radiant energy. With air temperatures below 45° F. it was found impossible to get comfortable between the extremes of intense cold and scorching radiation. They concluded that the most comfortable conditions corresponded with an air temperature of about 55° F. in conjunction with the requisite intensity of radiation for warmth.

Fishenden and Willgress used sources of high-temperature radiation—a gas fire and an electric radiator respectively—in their tests referred to above. These authors, however, also carried out a number of experiments with special low-temperature radiators at a temperature of approximately 750° F., and found the same aggregate intensities of radiation were required as from the high-temperature sources. In fact, they commented that owing to the more uniform distribution of the radiation with height, the degree of comfort was higher than with either of the other two radiators. The intensity of the radiant heat with which Dr. Fishenden and Mr. Willgress were concerned, however, is so much below the intensity which can be endured that it is unlikely any material difference would be detected between the conditions produced by radiant heat of different qualities.

---

* F.R.B. Technical Paper, No. 12.

The point to be emphasised is that if there is available an additional source of radiant energy in a living room, comfort is attained with a cooler atmosphere and the conditions are found to be much more stimulating. This is, in part, a consequence of the effect of the cooler air on the respiratory organs. With cold air the mucous membrane of the respiratory passages contracts and there is an increased flow of lymph to the surface, whereas if the air is hot the membrane expands and the conditions set up are much more favourable for the development of the germs of colds and other ailments.

It has been mentioned already that it may not be possible to attain comfort even with radiant heat irrespective of the air temperature. The air even in the English climate can be too cool to permit of comfort being attained with the aid of a radiant fire. Whilst the effect may to some extent be accentuated by movement of the air, the movement in living rooms is generally so slow that it is the temperature of the room itself which is the determining factor. It must be remembered that radiant heat falls only on those portions of the body which can "see" the source. Thus, the face, shins, feet and hands may be warmed, while the calves, back of the arms and the neck are not receiving directly a supply of heat. Often when seated in an armchair in front of a fire, if the air temperature is too low, it will be found that the shoulders or the arms which project beyond the sides of the chair feel cold, and even the hands themselves may become uncomfortable if the occupant of the chair is reading a book.

With such modern types of heating appliance as permit of rapid and controlled variation in the output of radiant heat, it is, however, more easy to attain comfort than when there is dependence solely upon a source giving off convected heat. The rate of input of heat to the body can be increased, and although the energy may be absorbed on one side only of a limb, it will be found that the temperature of the reverse side is raised, just as when the hands are immersed in hot water the temperature is raised in other parts of the skin. (The point can easily be tested by holding the hand in front of the fire—the result is no doubt due to blood circulation.) With a high-temperature source of radiant energy available, the user gains the advantage of the stimulative effects both of the bombardment of the body by radiant heat and of the breathing of cool air.

With this introduction I want now to deal with the main part of my address, which concerns some of the reactions of the human body to radiant heat of appreciably higher intensity than has been considered in these introductory remarks.

We have seen that with air at a temperature of 55° F., comfort is attained with an intensity of radiant heat of 75 B.T.U. per sq. ft. per hour. This is equivalent to approximately 0.34 grm. cals. per sq. cm. per minute. Later I shall deal with the reaction of the body to radiant heat of intensity 7 to 10 times as great as this. With energy of such intensity it becomes of interest to consider whether there is any difference in the sensations produced by different sources consequent upon variation in the quality, as distinct from the quantity, of heat received on the body.

The Quality of the Energy Emitted by Different Sources.

The radiant heat emitted by any artificial source is very different from that emitted by the sun. Writers in the popular Press talk loosely of artificial sunshine, but a comparison of the emission spectrum of the sun with that of other sources will indicate that it is extremely difficult to produce a radiant energy exactly similar to that which reaches the earth from the sun itself. Although the artificial source of energy may be visibly or even dazzlingly hot, the major portion of the heat radiated is in the infra-red—that is to say, it is invisible radiant energy of a longer wave-length than that of the range we term "light." The slides which follow show emission spectra of the sun, a tungsten lamp, the clinical gas lamp, two gas fires and a dull electric radiator, and Table I. indicates the proportions of the emitted energy falling within certain arbitrarily selected ranges.

These computations are based on the spectral emission curves after applying the dispersion correction, but have not been corrected for the differential reflections in the mirrors of the spectrometer.

It may be asked whether the heating of our bodies effected by sunshine on a summer's morning differs markedly from that occurring in front of the fire in our living rooms in winter. If there is no difference in the effects produced by visible energy, short infra-red and long infra-red energy, then there might be no difference between the sensations produced by sunshine and artificial heat, were it not for the ultra-violet energy received from

TABLE I.

Source.	to 2μ	2-3μ.	3-4μ.	4-5μ.	5-6μ.	6-7μ.	7-8μ.
	%	%	%	%	%	%	%
Sun	90	6.9	1.6	1.2	0.3	0.0	0.0
Tungsten lamp in clear glass (100 W.) ..	69.7	22.0	5.8	2.0	0.0	0.0	0.0
Clinical Gas Lamp (disc type) ..	22.8	29.0	21.1	16.1	6.6	3.0	1.7
Cobble Beam gas fire	16.9	24.0	21.7	17.9	10.4	6.0	3.1
Thermo Beam gas fire	11.6	21.8	20.9	20.6	14.7	6.6	3.8
Dull red electric radiator	6.4	19.1	24.8	23.1	14.1	7.5	5.0

the sun. So far as domestic heating appliances are concerned, any effects due to ultra-violet energy can be ignored. It is, of course, true that the Bunsen flame emits energy extending down to a wave-length of 3,000 Angstrom units, and that the white-hot filament of a tungsten lamp has an emission spectrum extending into the ultra-violet, but the amount of the ultra-violet energy is so extremely small that its effects are negligible. Further, the intensity of the light emission of the tungsten filament is so high that glare is produced. On that score alone its use unscreened as a fire would be open to serious objection.

The skin of a person exposed to the sun ultimately becomes coloured brown. Generally speaking, the colour is uniform. If a naked or thinly clothed body is exposed to an artificial source of heat of sufficient intensity for a length of time, again a brown pigmentation results, but in this case the pigmentation is mottled. The general appearance of the colouring suggests that the effect which has caused this pigmentation, whatever it may be, is much more deep-seated in its action than that produced by the energy from the sun. The uniformity and sharp definition of the pigmentation caused by the sun, which is due to ultra-violet energy, suggests that it is a consequence of an effect on the capillary streams, whereas the mottled pigmentation produced by a fire may have its origin in some effect on the arterioles, which are more deeply seated. Both effects are probably stimulative.

The data in Table I indicate that there are appreciable differences in the emission from different artificial sources of heat. With the tungsten lamp used, the peak of the emitted energy was at 1.3μ, whilst in the case of the gas fire employed, the first peak was at approximately 2.3μ, and the energy emitted extends further into the infra-red. In the case of the dull red electric heater, the peak was at 3.7μ. The question to be considered is whether differences of this sort in the quality of the energy will lead to any differences in the sensations experienced when the human body is exposed to such sources.

The better to understand the experiments to be described, it will be as well at this stage to give a short description of the structure of the human skin.

Structure of the Skin.

On the outer surface of the body is the dead horny layer of the epidermis, which varies in thickness from 0.02 mm. to 0.5 mm., and underneath are the living cells of the epidermis, in layers of thickness corresponding to the horny layers. The total thickness of the whole epidermis varies in general between 0.1 mm. and 1 mm., but may be even thicker in some people. Beneath the living cells is the derma, or true skin, in which blood circulates through a closely woven network of capillaries, in streams about 0.01 mm. thick. The nerve endings are in the living cells of the epidermis and in the derma. The derma is in general of the same order of thickness as the epidermis. The total thickness of the skin (epidermis and derma) varies between 0.5 mm. and 3.0 mm., but on the back and shoulders it may attain thicknesses as great as 5 or 6 mm.

Lewis, in his book, " The Blood Vessels of the Human Skin and Their Responses," states that it is in the most superficial parts of the skin directly beneath the actively growing epidermal cells that the final and most dense network of small blood vessels is meshed, spread out in a thin but complete sheet lying a millimetre or less below the surface. Through this probably the whole of the blood supply to the skin ultimately flows, presenting almost a maximum surface for dissipation of heat.

Variation in Endurable Time of Exposure to the Energy from Different Gas Fires.

Of recent years we have made changes in the design of gas fires with the object of increasing the proportion of short infra-red energy emitted. We find that when the amount of short infra-red energy is increased, more prolonged exposure to a given intensity of heat can be endured and at the same time the exposure feels more comfortable. The effect of such a change in the quality of energy is tested in the following way :—

The two gas fires to be compared are arranged on a bench with suitable polished copper screens in front of them. In each of these screens there is cut a hole of 2½ cm. diameter, and on the side remote from the fire is arranged a felt-lined cradle at a suitable height to support a human arm behind the opening. The portion of the screen surrounding the hole is also felt-covered on the side remote from the fire. The positions of the fires are carefully adjusted so that the intensity of the energy passing through the opening in the screen is the same in each case. The naked arms of a number of people are then exposed in turn to each fire, the left arm to one fire and the right arm to the other. The person undergoing treatment is asked to comment on the sensations and to remove the arm when pain becomes acute, whilst a record is made of the comments expressed and the time. Results attained with a Thermo Beam fire (B) and a Cobble Beam fire (C) are summarised in Table II. It will be seen that although the times of exposure varied considerably, in all cases a longer exposure to fire C was endured than to fire B.

TABLE II.

RELATIVE TIMES OF EXPOSURE.

Subject.	Fire B.	Fire C.
	Secs.	Secs.
1. Female, fair	116	184
2. „ medium	120	153
3. „ „	133	244
4. „ dark	82	161
5. „ „	100	120
6. Male, very fair	141	167
7. „ fair	102	143
8. „ „	102	112
9. „ medium	100	131
10. „ „	88	108
11. „ „	224	245
12. „ medium to dark ..	131	153

PENETRANCY PER CENT.

	Brown Bakelite.	Clear Bakelite.	Horn.
Fire B	6.5	6.6	9.3
Fire C	7.5	8.4	11.5

The heat emitted by these two fires differs in the proportion of short infra-red energy it contains. (See Table I.) This difference is represented by the penetrancy figures at the bottom of Table II.

Variation of Endurable Time of Exposure with Intensity of Energy.

The intensities of the energy used in the tests just described were such as could be endured in some cases for periods up to 4 min., but the ability to withstand exposure varied appreciably with the subjects. It is of interest to know how the period of exposure which can be borne by a particular person varies with increase in the intensity of the energy from a particular source.

To test this point a series of experiments was performed in which an arm was exposed at different distances from the fire and the time recorded until the exposure produced the first sharp tingling sensation. This is a point which can be defined reasonably sharply after experience in this class of work. The individual whose arm was exposed to the fire merely reported his sensations, whilst another observer recorded the times with a stop-watch. In between each exposure approximately 15 min. were allowed to elapse so as to ensure that all sensation of pain resulting from the previous exposure would be relieved. Throughout the series of tests, however, the exposed part of the arm was in a flushed state. On the following day the *rôles* of the two experimenters were reversed. The results attained are plotted in the curves in Fig. 1. The left-hand curve relates to operator *A* and the other to operator *B*. It will be seen that each curve is regular, and we have the relation between intensity and time of exposure defined by an equation of the type

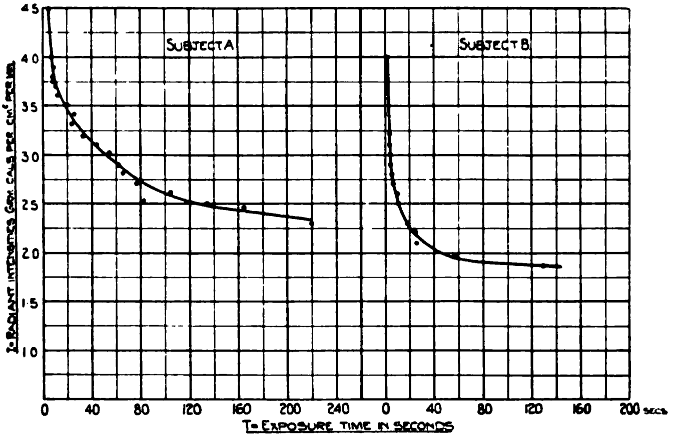


FIG. 1.

$$I\,T^x = \text{constant}$$

where I = intensity of the radiant energy falling on the arm,
and T = the time of exposure,

provided the intensity of the energy is adequate to produce the tingling sensation. It will be noted that the time of exposure required for *B* was less than that which *A* needed to produce the effect.

Threshold Intensity for Pain.

The experiments described in the previous section indicate clearly that when comparing the effects of radiant energy attained from different sources it is important to ensure, not only that comparative tests shall be made on the one person, but that care shall be taken to see that the intensity of the incident energy is accurately measured ; a small variation in the intensity when this exceeds a critical value having a big effect on the period of exposure which can be endured.

Tests have been made with a number of different appliances to determine a heat intensity which we describe as the *threshold intensity for pain :* that is, the minimum intensity of energy which produces persisting pain. The heating appliance to be tested is fixed on a bench with the perforated screen and cradle in front of it. The naked arm of the operator is rested in the cradle, and a series of tests is made to find the minimum distance from the fire at which the arm can be supported so that no persistent sensation of pain is felt in less than 3 min. The minimum intensity at which such pain is produced we have termed the *threshold intensity for pain.* Mr. U. C. Evans, who has carried out all the " comfort " experiments for us, either on himself or on other members of our staff, finds he is able to repeat his results to approximately 0.1 cals/sq. cm./min. on a given day. The tests are carried out with a flushed arm. Typical results are summarised in Table III.

TABLE III.

Source of Energy.	Threshold Intensity Cals./sq. cm./min.		Penetrancy % (Brown Bakelite).
	Sub. A.	Sub. B.	
Dull electric radiator	2.6	—	4.1
Thermo Beam gas fire at normal normal consumption	2.9	—	6.5
Cobble Beam fire normal consumption	3.1	—	7.5
Clinical Gas Lamp, disc type			
(a) normal consumption ..	3.2	2.03 2.08	1.8
(b) 100% pressure overload ..	3.4	2.30 2.30	14.1
Tungsten lamps in clear glass (no reflector)	3.7	—	31.3

We regard these results as of qualitative rather than of quantitative accuracy. The quantitative value of the intensity varies not only from individual to individual, but even with one person under different conditions.

The penetrancy figures in the third column refer to results attained with a screen of clarified brown Bakelite about ½ mm.

thick. Further reference will be made to this matter later, but at the present stage attention is drawn to the fact that in general the source of energy giving the highest threshold intensity is also that which gives the highest penetrancy value, although an increase in penetrancy relative to the Bakelite does not produce a proportionate increase in the threshold intensity.

Infra-red Transmission Spectra for Skin.

Fresh human skin contains a considerable amount of water, removable on heating to 105° C. In addition, the skin substance contains hydroxy radicles, so that the infra-red transmission spectra for the horny layer, the epidermis and the derma will reflect some of the characteristics of water layers. Julius, Paschen, Aschkinass and others have studied the transmission of radiant energy through thin layers of water and have found it extremely opaque to infra-red rays. Fig. 2 shows two curves obtained by Aschkinass, the one relating to a water film 0.1 mm. thick and the smaller curve to a film 0.05 mm. thick. Absorption bands will be found at 1.5μ, 1.9μ, 3.0μ, 4.5μ and 6μ.

We have measured transmission spectra for (*a*) moist rabbit bladder membrane. (*b*) clarified ox-horn, and (*c*) desquamated human skin. In order to avoid as far as possible error resulting from decrease of the water content of the bladder membrane during the experiment, the transmission determinations were made only at appreciable intervals. The results are plotted in Fig. 3. The

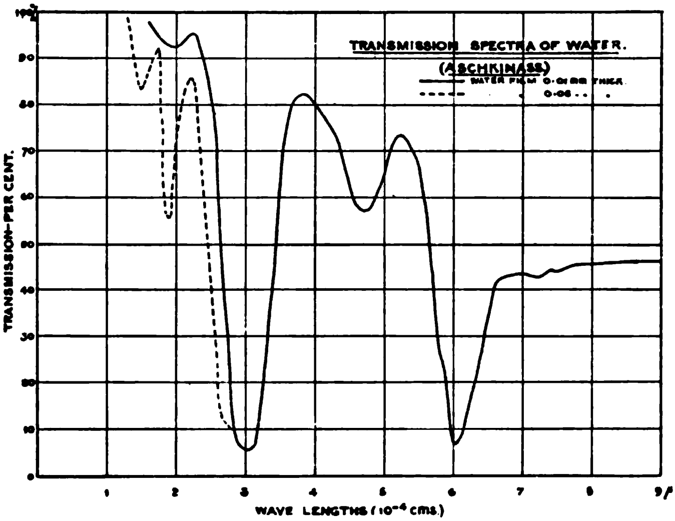


FIG. 2.

curve for desquamated human skin is known to be in error owing to scattering effects, which tend to lead to smaller penetrancy values with the shorter wave-length. It will be noted that all three substances show heavy absorption in the region 3.0μ-3.5μ, the moist rabbit membrane showing, in addition, sharply defined water absorption bands at 1.5μ and 1.9μ. More recently H. J. Taylor has published in the Proceedings of the Royal Society* a transmission curve for desquamated skin attained under experimental conditions arranged to eliminate scattering effects. The curve is published in Fig. 4. It will be noticed also that Dr. Taylor records strong absorption at 3μ, and that in general he found the shorter infra-red energy not much more penetrative than the infra-red energy longer than 3μ with which he worked.

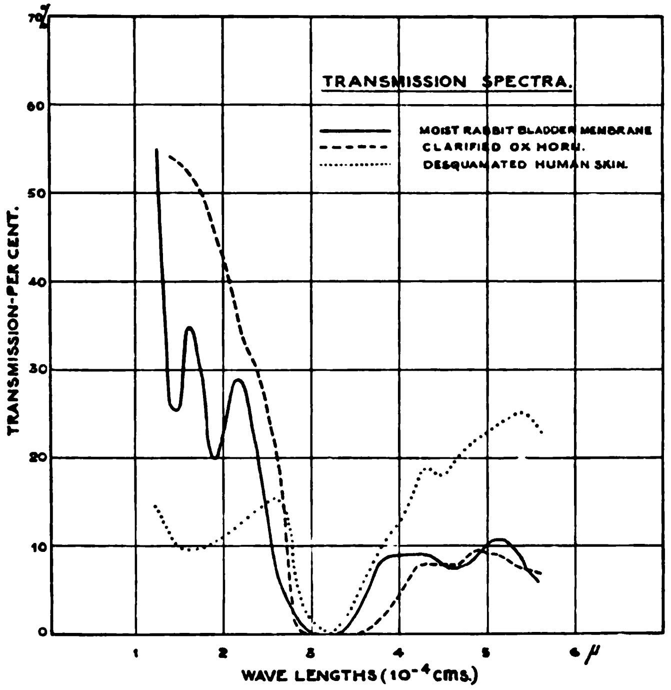


FIG. 3.

Transmission by Skin of Heat from a Gas Fire.

A consideration of the results represented by the transmission curves suggests that the longer infra-red rays may be very completely absorbed by moisture on the surface of the skin and in the upper living epidermal layers, whence heat would be transmitted subsequently to underlying tissues by conduction. The visible and short infra-red rays, on the other hand, are more penetrative and may pass directly to the living cells of the skin, and possibly also to the blood circulating in the capillaries. The visible red rays may, in fact, penetrate very deeply, not being wholly absorbed by the blood and tissues of the skin. For example, a glow-lamp held in the mouth in a dark room causes a faint red shine in the cheek of a white man. This does not occur with a negro. The pigment in the epidermis of a negro absorbs the visible rays and protects the blood from overheating.

---

* *Proc. Roy. Soc.*, A. vol. 142, 1933.

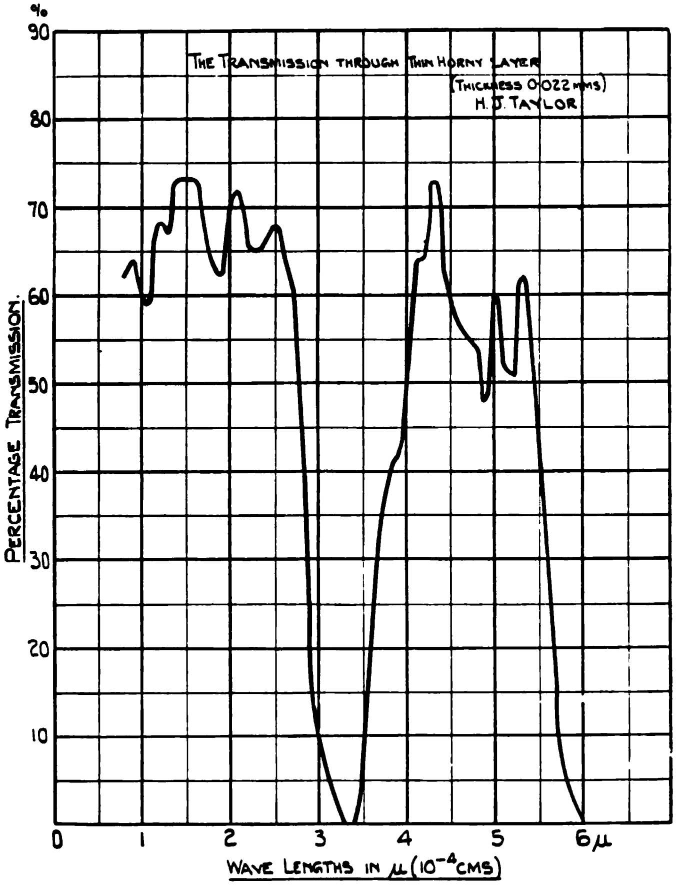


FIG. 4.

Experiments were carried out some years ago with a Thermo Beam gas fire to determine the amount of energy transmitted by different types of screen. Through the desquamated horny layer of human epidermis about 40 per cent. of the incident energy was transmitted, whilst through a piece of ox-horn about ¼ mm. thick the transmission was approximately 20 per cent. of the incident energy. Using the bladder membrane from a freshly killed rabbit, there was recorded transmission of some 14.6 per cent. of the energy at the moment of first exposure. Continued exposure of the membrane resulted in an increase in the amount of energy which was transmitted. Ultimately, after appreciable drying had taken place, the amount of transmission had increased to 45 per cent. With a piece of shaven stomach skin (epidermis and derma) from a freshly killed rabbit, the initial transmission was 6 per cent., whilst as the skin dried this increased to 20 per cent.

Three pieces of human skin (epidermis and derma, female breast), removed from an elderly patient during an operation, were examined and found to permit respectively of the transmission of 2 per cent., 1½ per cent., and 4½ per cent. of the incident energy from the same fire. These three specimens varied somewhat in thickness and possibly also in their water content. The whole of the under-fat had been removed from the skins, but the specimens were streaked with blood. Again, as drying took place there was a marked increase in the diathermancy of the samples. Our experiments have shown that the opacity of dead tissue to near infra-red and luminous energy at first decreases and then increases again with the passage of time.

Allowing for the thickness of the living human skin, it would appear that not only may a considerable proportion of the radiant energy from such a gas fire pass directly into the living cells of the epidermis, but some may also pass directly into the derma. The heating of the blood stream in the capillary vessels in and beneath and papillæ, resulting from the direct transmission of radiant energy, as distinct from that due to conducted heat, must, however, only be small for the more thickly covered parts of the body when the source of the energy is the particular fire under consideration. Where the skin is thin, as, for example, on the face, neck and forearms, which are usually exposed to the fire, there is, as indicated previously, a direct transmission of radiant energy even into the tissue below the skin.

Penetrancy.

In Tables II and III penetrancy figures are quoted for the energy emitted by the sources under consideration. These refer to results attained with clarified ox-horn or bakelite screens. It seems not unlikely that variation in the sensations felt under the action of radiant heat may be connected with the power of penetrating the epidermis possessed by the radiant energy. It is desirable, therefore, to have available means of measuring the penetrancy of the radiant energy relative to the human skin. Unfortunately, samples of skin lose water and also age when they are kept in the ordinary atmosphere, so that other screens have to be used as standards. We employ clarified ox-horn (⅜ mm.) and clear (1.3 mm.) and brown (½ mm.) bakelite. The transmission curve for bakelite is very similar to that of skin in the short infra-red, but more opaque to energy of wave-length greater than 3.5μ, whilst the clarified ox-horn transmission spectrum has been given already. In using screens of this kind it has to be remembered that there is appreciable absorption, so that when the screen is exposed to the source for any length of time it becomes heated, and thus an emitter of secondary radiation.

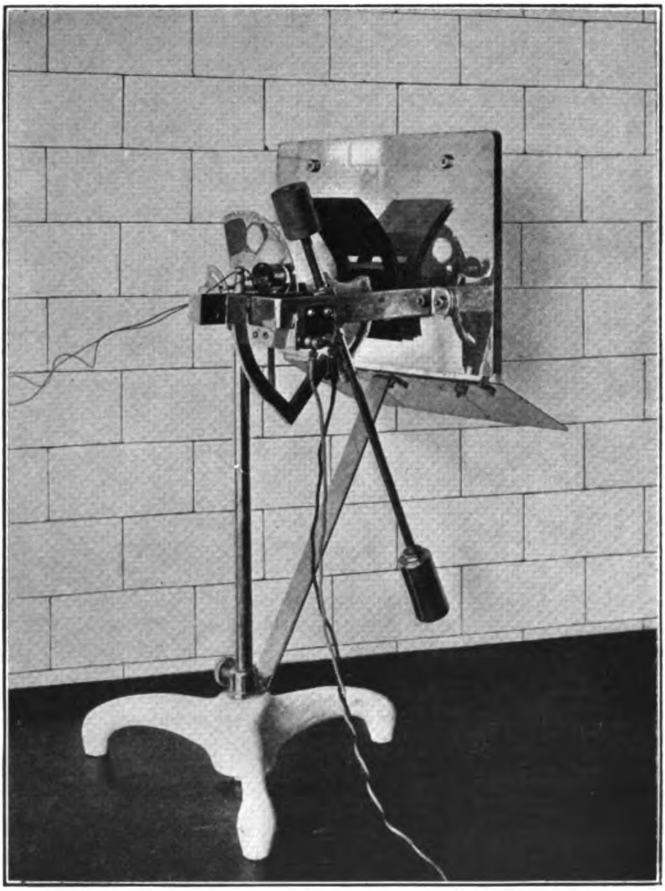


FIG. 5.

The apparatus we use for measuring the penetrancy is shown in Fig. 5. The screens to be used are fixed in the specimen holder, one of the openings being left uncovered. To measure the intensity of the incident and transmitted energy, a small Moll thermopile is employed, and this is clamped so that the hot junction face is just behind the specimen holder. The curved screen interposed between the thermopile and the fire is worked electro-magnetically, and is held in the " off " position when the current is flowing. To make an observation the current through the electro-magnet is broken momentarily, the screen then moves from in front of the specimen holder under the action of gravity and swings back again. When the magnet piece of the screen comes into contact again with the electro-magnet, it is held. In this way a controlled exposure of approximately ½ sec. duration is attained and direct heating of the specimen is avoided. The deflection produced on the galvanometer by the Moll thermopile is measured with and without the screen in position. The figures given in Table IV represent the percentages of energy from various sources which pass through the clarified ox-horn and bakelite screens.

TABLE IV.
PERCENTAGE PENETRANCY.

Source.	Brown Bakelite. (½ mm.) %	Clear Bakelite. (1.3 mm.) %	Horn. (⅔ mm.) %
Dull red electric radiator ..	4.1	3.4	5.4
Coal fire	5.9	5.5	8.1
Coke fire (bright)	6.8	6.9	9.8
Thermo Beam gas fire at normal consumption	6.5	6.6	9.4
High Beam gas fire at normal consumption	6.9	7.2	10.1
Cobble Beam gas fire at normal consumption	7.5	8.4	11.5
Incandescent gas mantle ..	8.3	11.9	14.4
Clinical Gas Lamp			
(1) Normal consumption ..	11.8	13.4	18.0
(2) 100% pressure overload ..	14.1	16.7	21.9
Tungsten (gas-filled) lamp			
(1) White sprayed	29.8	50.7	58.3
(2) Pearl	30.8	56.0	62.5
(3) In clear glass	31.3	57.5	64.5

Subcutaneous Temperatures.

We have made a number of determinations of subcutaneous temperatures in the hope that the results would provide information as to the cause of the effects due to variation in the quality of the energy. Unfortunately, however, we were not able to standardise the conditions to our satisfaction. Using two sources, one of which had a higher comfort factor than the other, we attained a number of results which seemed to show that the source with the higher comfort factor gave higher subcutaneous temperatures. On the other hand, we also attained a number of results which were directly contradictory. We found that the temperature which could be attained when continuing the exposure as long as was endurable was much influenced by the prior heating of the arm, whilst the pain due to the presence of the thermocouple (hypodermic needle) in the arm made it difficult to standardise the endurance limit.

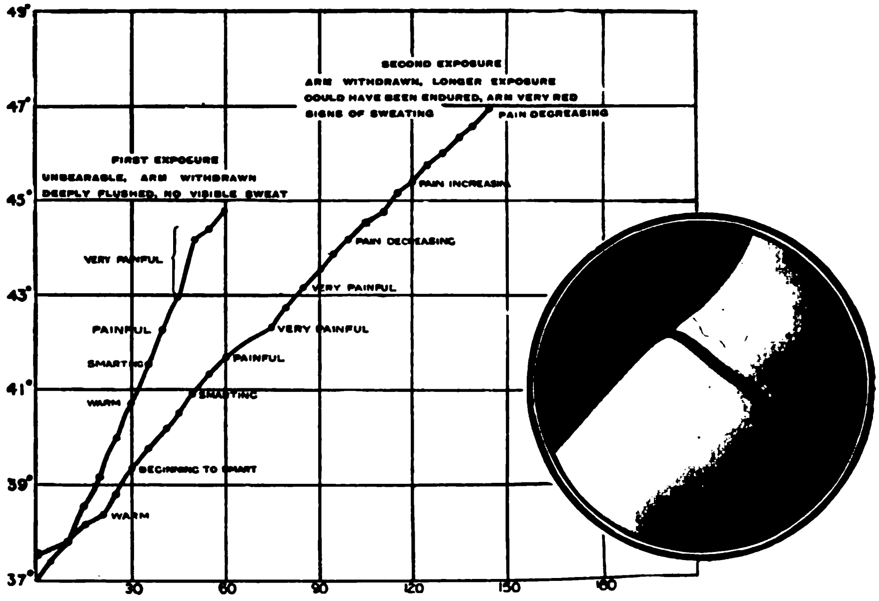


FIG. 6.

The curves in Fig. 6 represent the results recorded in two successive tests by the one experimenter. The subcutaneous temperatures were measured at a depth of approximately 2 mm. Between the end of the first experiment and the second a period of 20 min. elapsed, during which the arm was cooling down. In the first exposure the subcutaneous temperature rose very sharply, and the exposure had to be discontinued after 60 sec., at the end of which time the temperature had reached approximately 45° C. In the second treatment, the temperature rose to 49° C. The exposure lasted for nearly 3 min., and could have been continued longer.

The inset in Fig. 6 indicates the portion of the arm into which the needle was inserted, the area exposed to the heat being shown ringed. During the actual test the rubber band and wire connections were all shielded from the fire, only the area within the circle being exposed to the radiant energy.

Capillary Blood Flow and Comfort.

It seems not unlikely that the results recorded above are connected with the moisture content of the skin at the time of the exposure. We have found that certain prior treatments which induce an accelerated flow of blood in the surface capillaries increase the ability to endure in comfort the exposure to a high intensity of radiant heat. For example, excitation of the capillary flow by gentle slapping of the arm enables a more prolonged exposure to a high intensity of radiant heat to be endured. On the other hand, we have found that a restriction of the blood-flow induced by adrenalin injections leads to a decrease in the ability to withstand the effects of intense bombardment of the skin by radiant heat. Further, if the increase in the intensity of the radiant energy to which the arm is subjected is effected slowly, the threshold intensity for pain may be raised appreciably. When the arm is cold and dry, the sensation is less comfortable than when the arm is initially warm and moist.

Effect of Sweating on the Sensation of Pain.

An interesting experiment which threw light on the protective properties of the skin was carried out by a member of our staff. The experimenter exposed a portion of the arm (a disc of about 1 in. dia.) to heat, above his threshold intensity, from a gas fire. The body was shielded from the fire with the exception of the part of the arm under treatment. An observer recorded the sensations expressed by the subject, at the same time making a note of the period of the exposure. The results are summarised in Table V.

Table V.

Time of Exposure.	Remarks.
Start to 35 seconds	Pleasant sensation.
At 45 „	Pain beginning.
„ 58 „	Pain very acute.
„ 60 „	Pain declining.
„ 77 „	No further pain.
„ 104 „	Arm withdrawn: distinct sweating noticeable.

The experimenter had set out with the definite intention of blistering his arm, and after 58 seconds the pain became so great as to be almost unbearable. The exposure was continued, and there was recorded a complete cessation of pain. The part of the surface of the arm which had been exposed to the fire was examined and found to be covered with minute beads of perspiration. It was probably with the onset of the perspiration that the pain had disappeared.

An endeavour was next made to correlate the comfort and pain sensations with the amount of moisture on the surface of the skin. Two copper bands, each 2 cm. wide, were clamped at a distance of 3.8 cm. from one another round the arm of an experimenter. The copper bands were connected each to one of the terminals of a small Moll thermopile, which was exposed to a constant source of radiation, and thus made to generate a minute electro-motive force ; in the thermopile circuit was a suitable galvanometer. It was felt that variation in the current passing would give a qualitative indication of the amount of moisture on the surface of the skin. The experimenter sat near a gas fire with shields arranged so that, when desired, he could expose to the fire the portion of the arm with the copper bands on it.

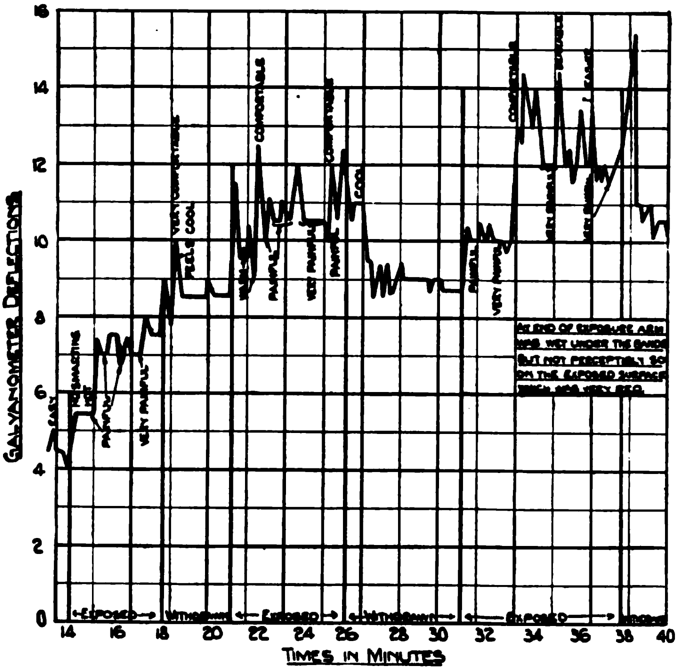


FIG. 7.

At first no current passed, but after the arm had been exposed and then shielded again a number of times, sufficient moisture had been brought near the surface to permit the passage of such current as could be recorded. The procedure consisted in exposing the arm for from 3 to 7 min. and then shielding it for from 2 to 5 min., recording at short intervals of time the sensations and the thermopile current. The experiment was continued for about three-quarters of an hour, at the end of which time the subject himself had become well heated, although only the arm had been exposed to the fire. The curve in Fig. 7 shows a part of the record of the test.

It will be noticed that during the periods of exposure the maximum deflections often coincided with the periods of relative comfort, whilst troughs in the curve corresponded with greater pain. Perfect agreement is not to be expected, as the experimenter had to record observations every few seconds, and there may also be a lag between the movement of the galvanometer needle, the emission of perspiration and the easing of pain, or the evaporation of perspiration and the onset of pain. When carrying out experiments on oneself it seems as though the sensation of pain increases and diminishes in surges. It will be noticed in some cases that after removal of the arm from in front of the fire there was recorded a sharp increase in the galvanometer reading. The effect of the prior treatment had set up perspiration, whilst removal from in front of the fire had decreased the evaporation which normally occurred during the heating period. The result on the whole supports the view that the sensations experienced when the naked arm is exposed to the fire are much influenced by the degree of moistness of the skin.

Conclusions.

The work which has been detailed briefly above leads to the following conclusions :—

1. Much higher intensities of radiant heat can be borne than are required usually for comfort in a living room.
2. The maximum intensity of heat that can be endured varies with the quality of the energy.
3. In general, the *threshold intensity for pain* increases with the penetrancy of the energy relative to human skin. This result is in agreement with Sonne's finding that a higher intensity of visible energy can be borne than of short infra-red energy, and of short infra-red energy than of long infra-red energy.
4. The *threshold intensity for pain* is affected by the general condition of the portion of the body exposed to the heat, being the higher the greater the capillary flow and the more moist the skin.
5. Under the influence of radiant heat, subcutaneous temperatures much higher than blood heat can be attained and maintained.
6. The effect of a heat treatment persists for some time after the end of the exposure, and even after the subcutaneous temperature (2 mm. depth) has fallen about to the original value.
7. Sweating relieves pain, provided permanent damage to the skin cells has not been caused.

MODERN METHODS OF ATTACKING HEAT TRANSMISSION PROBLEMS

By Prof. C. H. LANDER, C.B.E., D.Sc., M.Inst.C.E., M.I.Mech.E.

PAPER READ BEFORE THE INSTITUTION OF CHEMICAL ENGINEERS.*
LONDON, FEBRUARY 16th, 1934.

No apology is needed for choosing a subject of such wide application as heat transmission. There are few chemical engineering processes in which heat does not play a part, and the regulation and control of heat flow can be a very important matter for the chemical engineer. Unhappily, by reason of the very nature of heat transfer processes, it is often difficult to bridge the gap between theory and practice. It is none the less essential to seek law and order wherever possible, and to interpret what we observe in a scientific manner.

In endeavouring to analyse heat transmission the main trouble is that radiation, conduction and convection, which occur simultaneously, conform to entirely different laws. Further, these different processes, even when considered separately, are very complicated, and are affected by a large number of variable factors.

Radiation from Gases.

For instance, although the laws of radiation from solid bodies are fairly well established, very little is yet known about the radiating properties of hot gases. Furnace designers and furnace engineers have certainly realised that luminous or sooty flames might give intense radiation, but until quite recently it was generally assumed that non-luminous flames and gases did not radiate. A few years ago, however, Schack[1] pointed out that this was not consistent with laboratory determinations of absorption spectra, which would lead one to expect that even non-luminous gases, if at high temperatures and in thick layers, should be very important radiators. He showed, further, how the radiation from non-luminous flames or combustion products containing known proportions of carbon dioxide and water vapour could be calculated, the other constituents, viz., nitrogen, hydrogen, carbon monoxide, etc., either having no important absorption bands, or being present, under normal combustion conditions, in quantities so small as to be negligible. A wider knowledge of the importance of gas radiation is bound to have a great influence on the design of heat transfer apparatus.

---

*Published by permission of the Institution of Chemical Engineers, London.

[1] Schack, A., *Z. Tech. Physik*, 1924, Vol. 5, p. 267.

Owing to experimental difficulties Schack's theory has not been verified experimentally under practical conditions, small scale laboratory tests being of little use owing to the effect of size upon the heat transmission. Some measurements are at present being undertaken in the Mechanical Engineering Department of the Imperial College with the object of studying the radiation from non-luminous combustion gases on an industrial scale. To start with, a simple type of apparatus was erected consisting of a horizontal steel tube 5 ft. long and 1 ft. in diameter, through which combustion gases could be passed, and the heat transfer coefficient over the central 2 ft. length of the tube was measured.

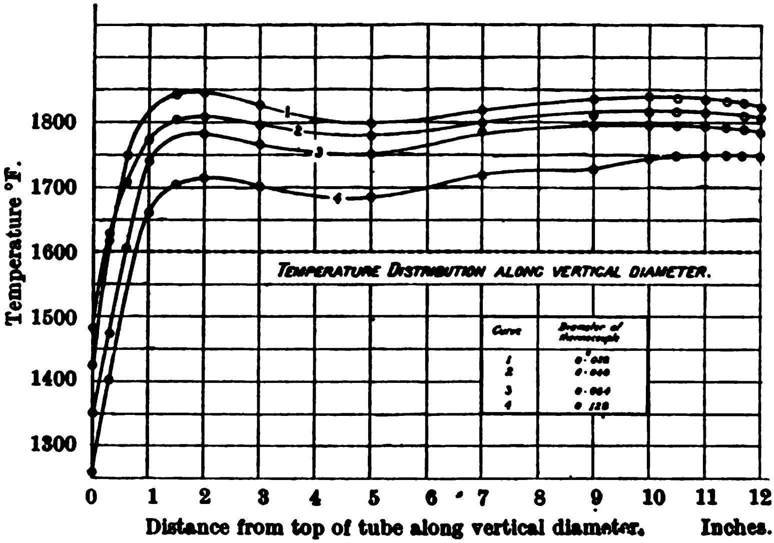


FIG. 1.

TEMPERATURE DISTRIBUTION ALONG VERTICAL DIAMETER AS MEASURED WITH DIFFERENT SIZED THERMOCOUPLES.

The determination of the gas temperature is made difficult by the effect of radiation between the cooler tube walls and the measuring thermocouples. Since, however, the convection heat loss per unit area from a wire is known to increase rapidly as its thickness decreases, while the radiation per unit area remains constant, an approximation to the true gas temperature can be obtained from the indications of a group of thermocouples of different sizes. Fig. 1 shows some typical results for the readings of four chromel alumel thermocouples, of wire diameter 0.022 in., 0.040 in., 0.064 in. and 0.128 in. respectively, in positions across a vertical diameter of the tube. The dotted line shows the corresponding mean temperature of the tube wall measured by embedded thermocouples. It will be seen that, as would be expected from the laws of convection, the temperatures indicated increase successively as the thickness of the thermocouple wires decreases. For all thicknesses there is remarkable uniformity over the central part of the tube diameter, for a distance which tends to increase as the thickness of the thermocouple decreases and which for the finer wires is at least five-sixths of the total.

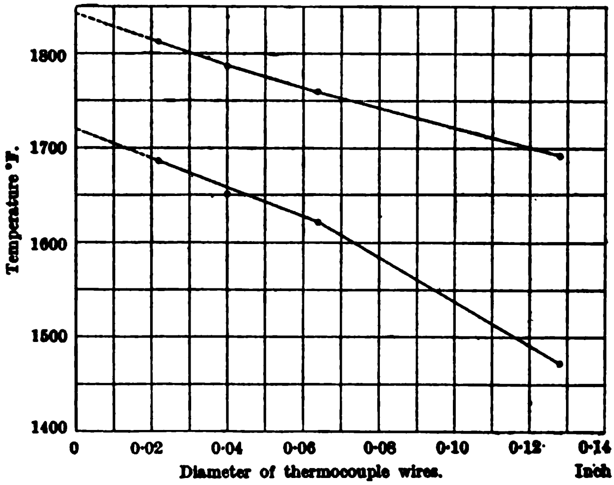


FIG. 2.

AVERAGE CROSS-SECTIONAL TEMPERATURES INDICATED BY THERMOCOUPLES OF VARYING SIZE AT POSITIONS TWO FEET APART ALONG LENGTH OF TUBE.

Owing to distortion of the tube which ultimately caused an elongation of about an inch in the vertical diameter, the thermo junctions when at their maximum distance of 12 in. from the top of the inside tube wall were still short of the bottom, and no readings were therefore obtained very close to the bottom of the tube. The temperatures indicated by the thicker wires in the zero position, i.e., flush with the inner tube wall at the top, are actually lower than the tube wall temperatures measured by the embedded thermocouples, and are evidently incorrect, but this is not surprising since at this point, where the tube was drilled for the entry of the thermocouple fitting, the conditions might well be upset. Further, the effect of conduction along the thermocouple wires would be to reduce their readings by a greater amount for the bigger diameters.

In Fig. 2 the cross-sectional averages of the thermocouple readings are plotted against the corresponding wire thickness, the upper and lower curves being for cross-sections 2 ft. apart along the length of the experimental tube. Down to the finest thermocouples the curves still show no tendency to turn over to a limiting value, but since the difference between the indications of similar thermocouples at the two cross-sections is practically constant for the finer wires, it was assumed to be very nearly the actual gas temperature difference and was used in the calculations. The practical uniformity of the gas temperature over the tube diameter made it unnecessary to measure the velocity distribution, the quantity of heat passing any cross-section being given nearly enough by the product of the mass velocity of the gases and their mean specific heat.

TABLE I.

HEAT TRANSFER FROM FLUE GASES.

Mean Gas Temp.	Mean Temp. Diff. Flue Gases. to Tube.	Mean Velocity of Gases.	Experimental Heat Transfer.	Gas Composition.		Calculated Heat Transfer.		
				H_2O.	CO_2.	Radn.	Convection.	Total.
°F.	°F.	Ft. Sec.	B.T.U. per hr. per ft. tube length.	%	%	B.T.U. per hr. per ft. tube length.		
1750	207	2.8	2590	7.4	17.1	3170	210	3380

Table I shows the preliminary results for the heat transmission, calculated values of radiation from Schack's absorption band data, and of convection from the most reliable experimental results, being included for comparison. The measured and calculated heat transmission coefficients are of the same order of magnitude, radiation accounting for more than 90 per cent. of the total.

Radiation and Furnace Design.—The design of furnaces has in the past been almost entirely empirical, scientific principles having been only very sparingly applied. The problem of getting the heat where it is wanted in the furnace is a very difficult one, and there is scope for much further progress. About ten years ago a book was published by a Russian engineer, Groume-Grjimailo, who attempted to apply the principles of convection to several types of annealing and re-heating furnaces. Although the treatment was by no means complete, and the book not of great use to the furnace designer, it was an enterprising attempt to break into a difficult subject. There is no reason why furnaces should not be constructed according to definite scientific principles, providing the data required are ascertained once and for all by appropriate experiment. It is clear, however, that radiation, both from combustion gases and furnace walls, which was neglected in Groume-Grjimailo's analysis, must be taken into account. For instance, the importance of radiation in the heating up of a charge in a furnace is shown in Fig. 3, in which are given the heating-up curves for two copper discs 6 in. in diameter by ½ in. thick in a gas-heated furnace. One of the discs was roughened and oxidised so as to absorb radiation strongly, while the other was gold-plated so as to absorb as little radiation as possible, and it will be seen that the black surface warms up much more rapidly than the gold-plated one.

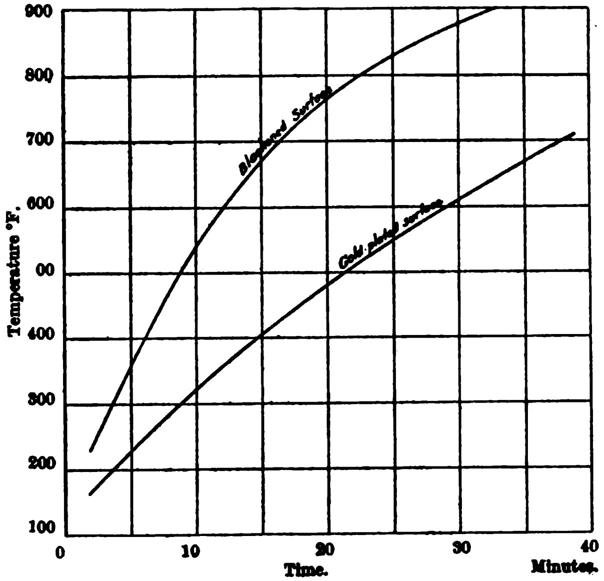


FIG. 3.

HEATING UP OF TEST SURFACES IN A FURNACE.

Convection.

Convection is fundamentally a very complicated process ; mathematical analysis of fluid motion has been confined mainly to non-viscous fluids, and in all cases the motion has been supposed to be stream-line. In practice the motion nearly always takes quite a different form, viz., turbulence, and a satisfactory mathematical theory of turbulence has yet to be found. In aeronautical problems designers have been compelled to resort to wind-tunnel experiments, but have been able to extend the scope of their results by means of the principle of similarity.

In convection the problem is one of fluid flow combined with heat movement. It is known that the fluid very near a surface is either stationary or in streamline motion, and until recent years investigators have reduced the problem of convection to that of conduction across the so-called stationary layer. This, however, is only a convenient method of expressing experimentally determined heat transmission coefficients, and is no advance towards a quantitative theory of convection, since the thickness of the boundary layer can only be deduced by working backwards from the experimental coefficients. More recent workers have perferred to follow the lead of aeronautical science, and have expressed their experimental results according to the principle of similarity. In 1930 Mr. O. A. Saunders gave a paper before the Junior Section of this Institution*, entitled " Heat Transfer Calculations," in which he showed how a mass of scattered experimental data could be brought into manageable form by this method. Its advantages are now becoming very widely recognised, and older and empirical methods are being generally abandoned in its favour.

The Principle of Similarity.—The principle of similarity has been used in many branches of science, for example, in dynamics, aerodynamics, strength of structures, motion of solids—e.g., ships through water, etc.—to correlate the properties of geometrically similar systems of different linear sizes. It is found to provide very useful information as to how the size and other variables affecting many problems may be grouped together.

A simple application of the principle is the old example of the fly and the elephant. It can be shown from the principle of similarity that the question whether or not any structure will collapse under its own weight is determined by the value of $\frac{g\rho l}{f}$ where l is the linear size of the structure, ρ and f the density and breaking stress respectively of the materials, and g the acceleration due to gravity. Thus if the elephant and the fly are supposed for simplicity to be exactly similar in shape and composed of material of the same density and breaking stress, the value of $\frac{g\rho l}{f}$ will be greater for the elephant than for the fly in proportion to the ratio of their linear sizes. It follows that, although the fly's legs may be strong enough to support its weight, the elephant may collapse unless its breaking stress is also greater in the ratio of the linear size, so as to make the value of $\frac{g\rho l}{f}$ the same for both.

An alternative way of achieving this would be to make the elephant's legs fatter in proportion to its size than those of the fly, and this is actually what is observed in nature.

The way in which the variables in any given problem are arranged to form a group is found by expressing the conditions that the dimensions, in terms of fundamental units of length, mass, time and temperature, must be the same on both sides of any equation expressing a physical law.

---

*Institution of Chemical Engineers.

One of the most important applications of the method is to problems of the flow of fluids past solids, which may be considered in terms of the well-known Reynolds' criterion $\frac{Vl}{v}$ where V is the fluid velocity, l the linear size of the solid and v the kinematic viscosity of the fluid. This has been applied to problems of aerodynamic resistance, and the resistance of ships moving through water, by means of models. For example, if a model of an airship on one-tenth linear scale were made and tested in water, which at 20° C. has a kinematic viscosity about one-tenth that of air, the value of $\frac{Vl}{v}$ would be the same for the model and its full scale counterpart for any given velocity. The value of the group $\frac{R}{\rho V^2 l^2}$, where R is the resistance force acting on the body, and ρ the fluid density, would, by the principle, be the same for the airship and for the water model, and the resistance for the airship could thus be found from measurements with the model. Although, in practice, the high velocities associated with airships could not be reached in water, the possibilities of prediction of the full scale behaviour from model experiments are greatly increased.

In the case of convection heat transmission, where, as already stated, the problem is one of fluid flow combined with heat movement, the conditions for similarity are more complicated. The use of models is, in almost all cases, ruled out because the conditions cannot be fulfilled simultaneously, but the principle shows how the variables may be grouped together and a saving effected in the experimental work necessary to discover their effects upon the heat transmission. For example, in the case of a tube cooled by an air stream flowing at right angles to its axis, the principle of similarity shows that the variables may be grouped in the form $\frac{Vcd}{k}$, where V is the air velocity, d the tube diameter, k the thermal conductivity of the air and c its specific heat per unit volume. For any given value of $\frac{Vcd}{k}$, the principle shows that the group $\frac{Hd}{k\theta}$ must also have a fixed value, where H is the heat transmission per unit area per unit time and θ the temperature difference between tube and air ; thus all experimental results are expressible in a single relation between these two groups. Fig. 4 shows the available experimental results for this case of convection plotted with these groups as co-ordinates. It will be seen that the experimental points, which were obtained with cylinders of diameter varying from 0.001 in. (fine wires) up to 6.0 in. (steam pipes), lie well on a mean curve, which can conveniently be used for practical calculations. In Fig. 5, in which additional points have been added to a curve given by

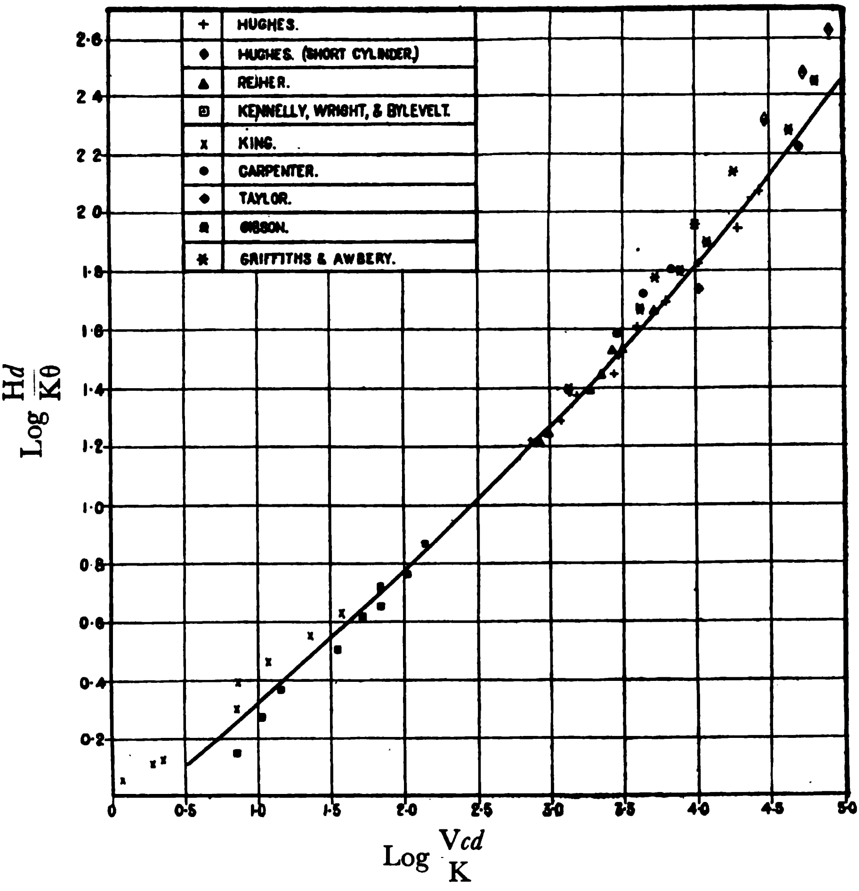


FIG. 4.

CORRELATED EXPERIMENTAL RESULTS FOR FORCED CONVECTION BETWEEN A CYLINDER AND A GAS FLOWING AT RIGHT ANGLES TO THE AXIS.

Mr. Saunders, is shown another example of the similarity method of correlating experimental results, this time for the natural convection heat loss from horizontal cylinders in still air, or other gas. The diameters range from fine wires to 10-in. steam pipes, and the temperature excesses up to 2000° F. for wires and 700° F. for large cylinders. A particularly interesting series of points in Fig. 5 is that from measurements of convection losses from wires in air, hydrogen, and carbon dioxide at high pressures. The experiments of Petavel were made under pressures up to 200 atmospheres. Since the values of $\frac{ag\theta d^3c^2}{k^2}$ which are the abscissæ in Fig. 5, increase as the square of the pressure, the size and temperature excess remaining constant, the points corresponding to high pressure experiments with wires fall on the same part of the curve as those corresponding to experiments with larger diameters at atmospheric pressure. The agreement of the results obtained under such different conditions is remarkably good, and is a striking testimony to the value of the similarity method. Recently experiments have been begun at the

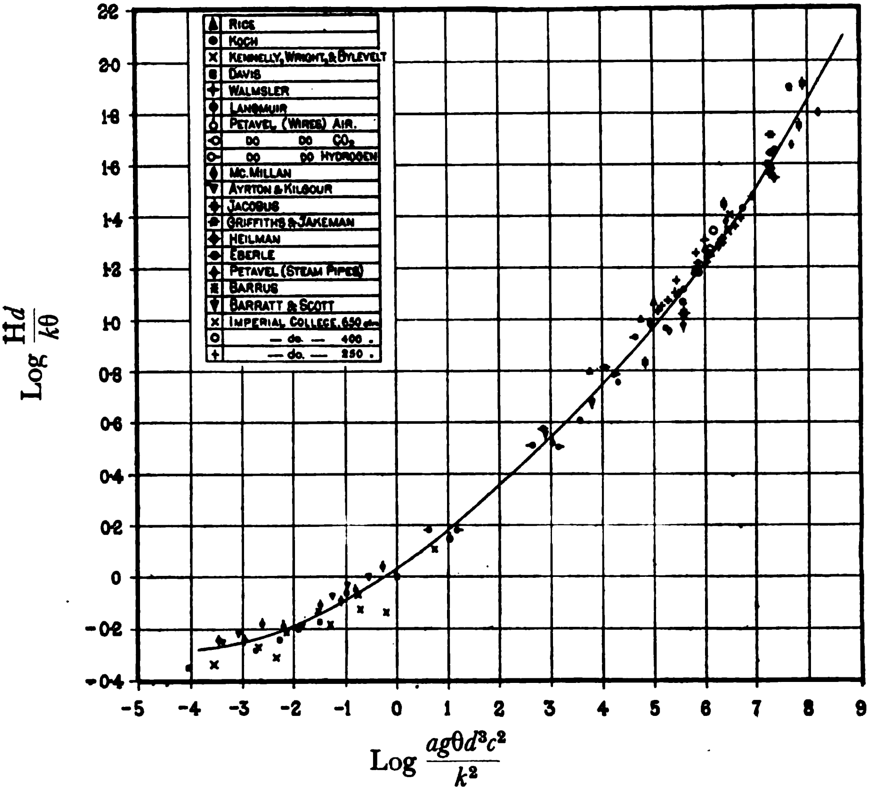


Fig. 5.

Correlated experimental results for Natural Convection from Horizontal Cylinders in Air or other Gas.

Imperial College, in which it is aimed to reach 1000 atmospheres; so far 650 atmospheres has been attained, and the results are shown in Fig. 5; they agree very well with the mean curve obtained from atmospheric pressure experiments.

These results firmly establish the reliability of the similarity method for predicting the heat loss under any given conditions of pressure. Hence, although these experiments were done, for convenience, with wires, they enable predictions to be made for larger diameters, which should be very useful in practical design of heat appliances where high pressures occur.

The similarity method often predicts the effect of varying a factor much beyond the range of direct experiment, and so gives valuable information without risky and unjustifiable extrapolating.

For example, from Fig. 5, taking the extreme end of the curve, the heat loss by convection from a wire in air at 3600 atmospheres can be calculated; it is found to 3.2 times that for the same wire at 650 atmospheres, the highest experimental value.

Effect of Shape upon Heat Transmission.—It is only for a few simple shapes, i.e., cylinders and planes for natural convection, and flow across cylinders and planes and through tubes for forced convection, that there are enough experimental results to be correlated even with the help of the principle of similarity. But the effects of shape, which of course helps to determine the nature of the fluid motion around a body, may be so important that fuller and more systematic investigations are urgently needed. Even among the few cases quoted there are outstanding discrepancies.

It might, for instance, be expected that the heat loss per unit area from a cylinder of streamline cross-section in a current of air would tend towards the corresponding value for a plane surface as the width of the cylinder perpendicular to the direction of flow is decreased to vanishing point. The results of Hughes,[2] with a streamline cylinder 0.8 in. wide and 4 in. long, and of Bryant,[3] with a streamline cylinder 0.4 in. wide and 6 in. long, do not confirm this (Table II). But so little is known as to how far differences in shape, length in the direction of air flow, and air flow conditions, may affect the heat loss, that it is not wise to attach much significance to such an apparent discrepancy; it does, however, show the need for further work.

Again, it is known that the heat transfer between the internal surface of a tube and a gas flowing through it decreases as the diameter increases. For very large diameters it would be expected to approach a limiting value equal to the corresponding value for plane surfaces; but over the experimental range, the heat transfer for flow through a tube steadily decreases as the diameter increases, and at 1 ft. diameter, which is the limit of the experimental range, has already fallen 50 per cent. below the plane surface value (see Table II).

---

[2] "The Cooling of Cylinders in a Stream of Air," *Phil. Mag.*, 1916, Vol. 31, p. 118.

[3] Reports and Mem. Aeronautical Research Comm., 1928, No. 1163.

TABLE II

COMPARISON OF THE HEAT TRANSFER BY FORCED CONVECTION FOR FLOW THROUGH A TUBE, OVER A PLANE SURFACE, AND OVER STREAMLINE CYLINDERS.

	Heat Transfer in B.T.U./ft.^{2}hr. °F.		
	Diameter 0.1 ft.	Diameter 0.2 ft.	Diameter 1.0 ft.
Flow through tube	10	8.5	6.2
Flow past plane surface		9.1	
Flow past streamline cylinders:—			
Hughes		10.5	
Bryant		4.5	
Ditto (Hughes) wrong way round ..		7.4	
Flow past circular cylinder of same surface area		9.5	

A possible explanation is that the length of the tubes was always much greater than that of the plane surfaces and the heat transfer is known to decrease with increasing length, but the evidence is too uncertain to allow of a quantitative correction.

Effect of Turbulence.—It is generally agreed that turbulence aids heat transfer, and it has been found that devices inserted in a fluid stream to induce turbulence prior to its incidence on a surface increase the heat transfer coefficient. Reiher,[4] for instance, found that the heat transfer between the external surface of a cylinder and a stream of air flowing at right angles to its axis at velocities of 6 to 15 ft. a second was about doubled by placing two rows of staggered tubes to windward. He obtained similar results with tube-bundles, in which, with staggered arrangements of 0.6 in. diameter tubes in rows respectively 0.8 in. and 1.1 in. apart, the third and subsequent rows gave much higher rates of heat transfer, tending to about 50 per cent. increase, although in the former arrangement there was a decrease of 14 per cent. from the first to the second row. In square formation, tubes of diameter 0.6 in. arranged in rows just over an inch apart, gave about 25 per cent. less in the second than in the first row, but in subsequent rows the transfer was about the same as in the first row.

---

[4] See Fishenden and Saunders, "The Calculation of Heat Transmission," pp. 130 and 136-7.

Griffiths and Awbery,[5] in a recent paper before the Institution of Mechanical Engineers, described measurements on banks of iron pipes of $1\frac{29}{32}$ in. diameter. In the square formation, with parallel rows 3.2 in. apart, there was an increase in heat transfer from the first to the second row which rose steadily with the velocity to 31 per cent. for the highest velocity recorded—i.e., 20 ft. a second. There was no further increase in the third or later rows. With the square formation rotated through 45° with respect of the air stream, bringing it into staggered formation with parallel rows $2\frac{1}{4}$ in. apart, the heat transfer increased successively from the first to the second, and from the second to the third row, after which it remained constant, at a value about 65 per cent. above that for the first row. The authors suggested " that the air was set in a definite state of eddy motion in the first layer, and that the second layer added to the general turbulence, the process being completed after the third layer." By making the air turbulent before it impinged on the tubes, the heat loss even in the first row was increased above the limiting value for a number of rows without artificial turbulence, but there was no further increase in subsequent rows.

Streamline Surfaces.—It may seem anomalous that, whereas heat transfer can be increased by promoting turbulence, it is also high for cylinders of streamline section. For instance, Hughes' streamline cylinder with the air stream incident on the rounded end lost about 10 per cent. more heat than a circular cylinder of the same surface area. Further, when the streamline cylinder was turned round so that the air stream was incident on its pointed end, its heat loss was reduced by 30 per cent. This presumably is to be explained by the existence of a dead zone in the wake of a circular cylinder, whereas the air stream clings to the streamline section throughout its length. If the heat transfer for a streamline cylinder is compared with that of a circular cylinder of the same air resistance the difference is much more striking, the ratio being about 7 to 1. The theoretical relationship between heat loss and skin friction, which has been worked out by Reynolds, Prandtl and others, helps in the interpretation of these results. The heat loss is proportional to the skin friction, which if the air motion is everywhere streamline, is responsible for the entire resistance. On the other hand, when the motion is turbulent, energy is spent in setting up eddies and the total resistance is greater than the skin-frictional resistance. A cylinder of streamline section is designed to create a minimum amount of eddying, even when the velocity is much above the critical value ; consequently the heat loss should be very nearly proportional to the total resistance, whereas for a circular cylinder the heat loss for the same resistance is much less.

---

[5] " Heat Transfer between Metal Pipes and a Stream of Air," read December 15th, 1933.

This point has an important bearing on the design of cooling surfaces in aeroplanes, etc., where the resistance must be reduced to a minimum, and it would be interesting to try tubes of streamline section in heat exchangers.

Effect of Roughness.—The effect of roughness on heat transfer is another important practical consideration. Roughness could, of course, be regarded theoretically as a shape factor, but no experimenter has so far been ambitious enough to maintain geometrical similarity so perfect that the grade of the roughness was proportional to the linear dimensions. The frictional resistance of a surface can be greatly increased by roughening, but it is by no means certain that a corresponding increase in the heat transfer would follow; for very low velocities, indeed, roughness might even decrease heat transfer owing to the insulating effect of air trapped in the cavities.

Stanton at the National Physical Laboratory, for forced convection in a brass tube of 1⅛ in. diameter with intersecting grooves 1/100 in. deep, obtained values more than twice those for a smooth tube under the same conditions; but some further experiments showed roughening the gills of an air cooled internal combustion engine to have no appreciable effect. Again, Reiher found that a grooved tube gave less heat transfer at low velocities, and more at high velocities, than a smooth tube. Most experimenters have found the heat transfer to be higher between a rough than a smooth plane surface and a stream of air, but Ott obtained lower values for a rough surface than for a smooth one at velocities below 15 ft. a second, and higher values at velocities above 15 ft. a second.

Some systematic experiments on the effect of different grades of roughness on the heat transfer between a plane surface and an air stream are in progress at the Imperial College.

Optical Measurements of Convection Heat Loss.—For the purpose of investigating the effects of shape and size on the natural convection heat loss from hot surfaces in air, an optical method has been developed at the Mechanical Engineering Department of the Imperial College, following on the lines of the photographic method of E. Schmidt. A ray of light is sent parallel and very close to the hot surface, e.g., a horizontal flat surface, and becomes bent away from the surface, as it passes over it, owing to the gradient of refractive index, caused by the gradient of temperature, normal to the surface. By measuring the deviation on a suitably placed screen, the temperature gradient, and hence the heat loss from the surface to the air, can be deduced.

Fig. 6 shows a photograph obtained by the method with a horizontal plate 18 in. by 9 in. The light has been limited to within about 1 mm. of the plate surface, both on the top and on the under side. The displacement normal to the plate of the lines from their position when the plate is unheated is a measure of the convection heat loss. The photograph was a time exposure, and the top line appears fuzzy because of its oscillation up and down owing to the turbulent air conditions above the plate. It can be seen that the top surface loses much more heat than the bottom, and that the top distribution is fairly uniform, while the bottom distribution increases towards the edges. The effect of baffling surfaces, and of varying their absolute size is now being systematically studied.

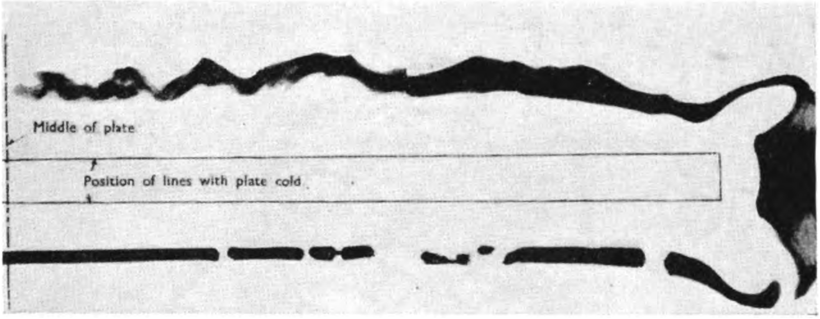


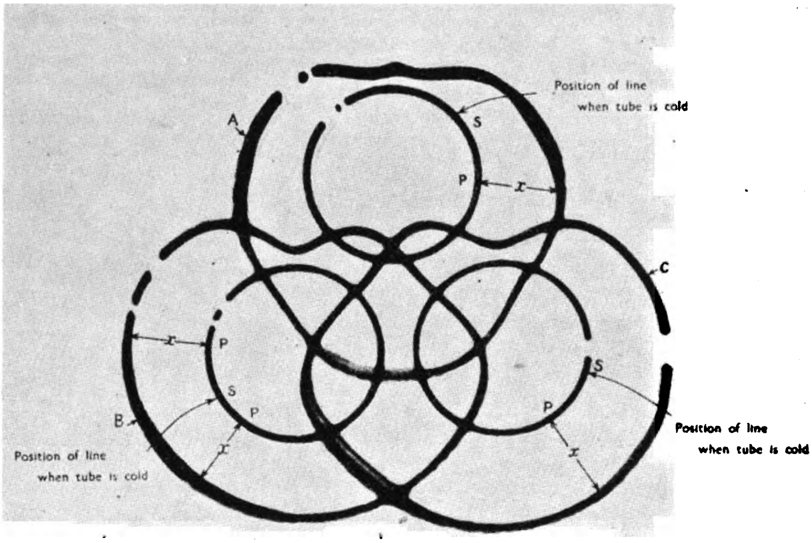
Fig 6.

Opitical Method of Measuring Natural Convection Heat Losses from Top and Bottom Surfaces of a Horizontal Plate in Air.

Fig. 7 illustrates the application of the optical method to three heated horizontal cylinders, of diameter 2 in., in triangular formation. The effect of one tube on another as regards the distribution of the heat loss is clearly shown, the rather striking fact appearing that two adjacent hot bodies can cool one another. The mean loss from either of the lower tubes is found to be nearly the same as when isolated, the higher losses at the adjacent faces being balanced by the lower losses near the tops. The top tube loses much more heat from its underside, presumably owing to the increased velocity of the air rising between the two lower tubes, but its mean loss is found to be only slightly greater than for the lower tubes. If, however, the top tube were bounded by tubes on either side, it would probably lose more heat. These results are only preliminary, and systematic studies of several cases are in progress.

The optical method has been proved to give quantitative results at least as accurate as those obtainable by any other methods ; but its great advantage is that the distribution of heat loss, as well as the total, can be observed instantaneously for either streamline or turbulent conditions. Also the necessity for lagging, as, for instance, in studying the separate losses from the top and bottom of a horizontal flat surface by the electrical input method, is removed. This is sometimes important, since lagging not only introduces awkward corrections, but may alter the shape or dimensions and thus disturb air flow conditions.

One of the limitations of the optical method, of course, is that it can be used only with surfaces generated by a straight line pointing in a fixed direction, e.g., plane surfaces, or cylindrical surfaces of any cross-section.



TUBE DIAMETER, 2" SEPARATION, 1"

FIG. 7.

OPTICAL METHOD OF MEASURING NATURAL CONVECTION HEAT LOSSES FROM THREE HORIZONTAL CYLINDERS IN TRIANGULAR FORMATION IN AIR.

The method has been shown to be applicable to convection in liquids. So far it has been tried only for natural convection from a vertical plate, but there are possibilities of its extension to forced convection, although difficulties arise owing to the smaller thickness of the boundary layer.

Many other important problems in heat transfer still await investigation. The whole subject is indeed like a jig-saw puzzle in which only a few pieces have yet been fitted into place. Such a paper as this can thus obviously make no claim to be comprehensive ; its object is rather to give a glimpse of some of the better assembled fragments of the puzzle and to make suggestions as to possible key pieces. It is only by trying to view the subject in this way that further efforts can be guided into such directions as may reasonably be expected to give the best return for the least expenditure, and help most quickly to convert a perplexing mass of scattered material into a meaning whole.

The author desires to thank Dr. Fishenden and Mr. Saunders for their help in preparing the paper and for the results of experimental work obtained by them and their assistants, particularly Mr. J. A. Lindsay on gas radiation and Mr. A. T. Brook on convection at high pressures, in the Mechanical Engineering Department of the Imperial College.

Acknowledgment is also due to the Worshipful Company of Clothworkers, the Department of Scientific and Industrial Research, and the Gas Light and Coke Company, for grants which have made possible work on heat transmission and furnace design on so wide a front.

Building Research Station, Garston, Nr. Watford, Herts.

THERMAL PRECIPITATION OF DUST

By A. F. DUFTON, M.A., D.I.C.

Fifty years ago, in 1884, Mr. John Aitken showed experimentally that dust not only tends to move away from hot surfaces, but also that it is attracted by cold ones and attaches itself to them.[1] He pointed out that this explains a number of familiar things, among others, why the walls and furniture of a stove-heated room are always dirtier than those of a fire-warmed one ; in the one case the air is warmer than the surfaces, and in the other the surfaces are warmer than the air. Aitken demonstrated that the hot surface repels because the outward diffusing molecules are hot and have greater kinetic energy than the inward moving ones ; and as the side of the dust particle next the hot surface is bombarded by a larger number of hot molecules than the other side, it is driven away from the hot surface. The cold surface attracts because the outward diffusing molecules have less kinetic energy than the inward moving ones.

Aitken's investigations afford a sufficient explanation of the stains upon plaster ceilings which so clearly reveal the pattern of the construction behind the plaster and it is curious how little his work is known and how widespread the idea is that the pattern-stains are due to dust left behind by air which has passed through the plaster. The prevalence of this notion seems to be due to Sir Douglas Galton, F.R.S., who wrote,[2] "The ceiling affords a ready instance of porosity; an old ceiling is blackened where the plaster has nothing over it to check the passage of air, whilst under the joists where the air has not passed so freely, it is less black.

---

[1] Aitken, J. On the Formation of Small Clear Spaces in Dusty Air, Proc. Roy. Soc. Edin., 1884, 12, 440.

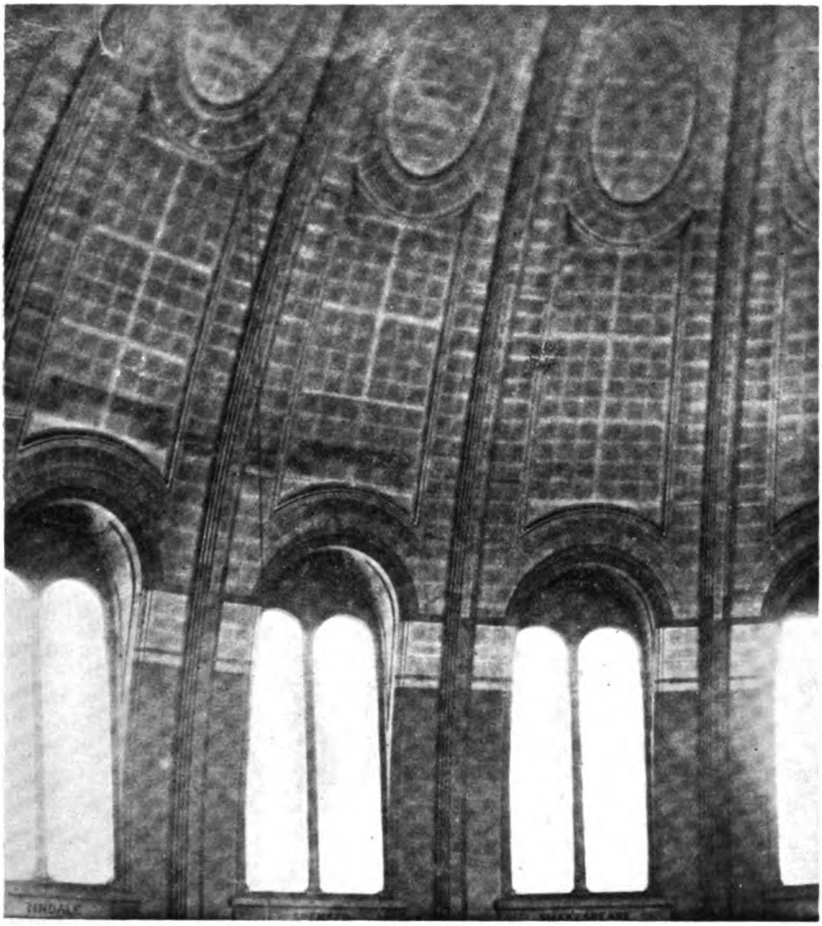


FIG. 1.—AN EXAMPLE OF PATTERN STAINING

---

[2] Galton, D. "Observations on Healthy Dwellings," 2nd. Ed., London, 1896, p. 55.

On breaking the plaster, it will be found that its blackness has arisen from its having acted like a filter, and retained the smoky particles while the air passed through."

This is very plausible. That it is a fallacy, however, has been demonstrated by definitely preventing filtration through the plaster by the insertion of a layer of lead foil. This did not make any appreciable difference to the pattern produced on a lath and plaster ceiling. That the fallacy has persisted is particularly strange in view of the fact that in 1905 the true explanation was clearly given by Prof. W. F. Barrett, F.R.S.,[3] in his paper "On the Heating of Buildings and on Dust Deposition." Prof. Barrett pointed out that where it is not backed by a wooden lath, which is a bad conductor of heat, the plaster is cooler and hence the dust leaves the parts where the wood is and attaches itself to the other parts of the surface.

Very many inquiries have been addressed to the Building Research Station on the subject of pattern-staining and a bulletin[4] has been issued describing practical means of overcoming the trouble and demonstrating the precautions to be taken in new building work. Fig. 1 is reproduced from this bulletin.

---

[3] Barrett, W. F. I.H.V.E. Report, 1905-1906, p. 103.

[4] Building Research Bulletin, No. 10, The Prevention of Pattern Staining of Plasters, H.M.S.O., 1931, 4d. net.

COPPER AND DRINKING WATER

Dear Sir,—With reference to Vol. 2, No. 18, page 265, of our *Journal* regarding the use of copper for drinking water, etc., we have at present several jobs on hand where this material is being used, and as we were very much interested in your article we had the data given checked by a very good firm of analysts by the name of Messrs. McGowan & Biggart, Greenock.

We are so surprised by their findings that we are enclosing herewith their report which we think you should immediately publish to prevent any erroneous misinterpretation in the trade.

Yours faithfully,
Wm. Kerr, A.M.I.H.V.E.

10 Virginia Street, Greenock.

[Owing to a typist omitting a decimal point in Mr. W. L. Kilburn's original manuscript, lines 4 and 5 from the bottom of the page should read " In drinking water, 0.14 part per 100,000 of copper is found to be quite free from any suspicion of danger," and not " 14 parts per 100,000." Will members kindly make the correction to obviate a repetition of the error. The following extract from the report of Messrs. McGowan & Biggart may be of interest : " Although metals are usually present in waters as salts, it is usual in a water analysis to express them in the metallic form. To give 14 parts of copper per 100,000 would require 38.71 grains of copper sulphate per gallon, so therefore a quart of such water would yield 9.67 grains. The emetic dose of copper sulphate is from 5 to 10 grains, so therefore 1 quart of this water would furnish nearly the maximum dose. We would therefore expect a water containing 14 parts copper per 100,000 to cause vomiting if drank in moderate quantity. We actually tried it out by adding the quantity of copper sulphate to the water and we found that the water was quite green in colour, and very astringent in taste, almost undrinkable. It would be impossible for any ordinary water to dissolve copper to the extent of 14 parts per 100,000 from any copper piping. Although there is no evidence against small quantities of copper in industrial water it is better to stop if possible the action of water on copper pipes. Traces of copper interfere greatly with the colour of many organic preparations. It is also asserted that in many dairy preparations that small quantities of copper affect taste and appearance. It should also be remembered that the Ministry of Health have banned copper as a food colouring and preservative. If the article had stated decimal one four part of copper per 100,000 we should have had no difficulty in having complete agreement with the article."—Editor.]

ABSTRACTS

Aluminium Foil and Heat Loss. 536.2

The values which have been accepted for surface conductances from building materials may be reduced when using surface finishes which have a high resistance to radiant heat. The reduction will depend upon the emissivity of the surface and upon the mean temperature between the surface and the surrounding objects. It will be independent of air velocity over the surface. For average conditions of aluminium surfaces which are highly polished, it would seem reasonable to make reductions in the transmission coefficients as shown in table for the different mean temperatures. These reductions, however, cannot be followed blindly, due to the many variables which enter the problem.

TABLE I.

REDUCTION IN AVERAGE SURFACE TRANSMISSION COEFFICIENTS CAUSED BY COVERING THE SURFACE WITH BRIGHT ALUMINIUM FOIL.

Mean Temperature, Deg. F.	Reduction in Coefficient, B.T.U.
20	0.559
40	0.634
60	0.711
80	0.797
100	0.887
120	0.99
140	1.09

It may be said that the general accepted coefficients for wall surfaces and for air spaces which involve surfaces should be revised if special materials with low emissivity coefficients are to be used for surface linings. The reduction will depend upon the surface characteristics of the material. If the emissivity coefficient is known, the correction can be made with reasonable accuracy by calculation. (F. B. Rowley. *Heating, Piping and Air Conditioning*, June 1934.)

Friction of Leather Belting. 622.445.62

There is much diversity of opinion regarding the working coefficient of friction, but in general it depends upon the material of the belt and the condition of the belt, the permanent slip, whether the load is steady or fluctuating, the diameter of the pulley and the material of which it is made, and the speed of the belt. In view of the foregoing, the coefficient of friction cannot be assumed as an average for all speeds, as is so frequently done in belting calculations. It is practically impossible to devise an expression for u in terms of all the factors mentioned above, but the following formula proposed by Mr. C. G. Barth has been found to give fairly satisfactory results in practice for leather belting on cast-iron or steel-rim pulleys :—

$$u = 0.54 - \frac{140}{500 + V}$$

in which V represents the velocity of the belt in feet per minute. (*The Modern Engineer*, May 20th, 1934.)

Economics of Insulation. 536.2

The domestic coal stoves and heating appliances at present in use deliver to the house interior at best only 60 to 70 per cent. of the total heat in the fuel and the economic use of the available heat is almost entirely a matter of efficient insulation.

In cold storage and refrigeration plants where a temperature is maintained from 10 to 80° below the outside temperature, it is found economical to use anything from 6 in. to 8 in. thickness of highly insulating material, yet the majority of householders in this country attempt to maintain similar temperature differences in the winter without the provision of any effective insulation whatever.

Provision of suitable insulation in houses effects a saving in fuel costs of anything up to 40 per cent. and the cost of the installation of the thermal insulation is usually recovered in the first heating season.

The cost of insulating a new house will vary considerably according to the variety and thickness of insulating materials used, but it seldom exceeds 5 per cent. of the total cost of the building.

The fuel saving in tons of coal per annum can be calculated by the following formula :

Annual fuel saving in tons of coal =

$$\frac{T_0 - T_1 \times H \times t \times A}{C \times E \times 2240}$$

Where T_0 is the coefficient of heat transmission of the uninsulated construction in B.T.U. per hour per sq. ft. per deg. F. difference in temperature.

T_1 is the coefficient of heat transmission of the insulated construction.

$(T_0 - T_1)$ is the B.T.U. saving per hour per sq. ft. per deg. F.

H is the number of hours duration of the heating season (usually taken as 5,040 hours).

t is the temperature difference (for roofs this is usually taken as 35 deg. in this country).

A is the area of construction considered (sq. ft.).

C is the average calorific value of the coal (say 12,000 B.T.U. per lb.).

E is the average heating efficiency of the installation when burning coal (say 50 per cent.).

(C. W. Glover, *The Architects' Journal*, July 5th, 1934.)

Dusty Trades. 628.511

The following table is a summary of the average dust content of the air in certain dusty industries :

AVERAGE DUST COUNT IN CERTAIN DUSTY TRADES.

Industry.	Dust count in millions of particles per cubic foot of air.
Slate Finishing Mills	
Floormen	1598.0
Loaders	1276.0
Disc crusher operators	312.8
Talc Mining	
Jack-hammer drillers	2159.8
Muckers	44.8
Talc Finishing Mills	
Crushers and cylindermen	14.0
Packers	50.1
Marble carvers	19.1
Marble cutters	32.8
Granite Quarrying	
Leyner drillers	144.4
Jack-hammer drillers	112.1
Plug drillers	36.9
Cement Mill, average of all operations	26.0
Granite Cutting	
Hand pneumatic tool operatives	59.2
Machine pneumatic tool operatives	35.9
Attendant labour	17.0
Anthracite Coal Mining	
Miners and miners' helpers	231.5
Attendant labour	31.1
Bituminous Coal Mining	
Coal cutters and coal loaders	112.3
Attendant labour	3.9
Silverware Manufacturing	
Dusty processes	5.2
Non-dusty processess	1.7
Municipal Dust (Street Cleaners)	
Congested district	4.1
Residential district	1.8
Cotton Industry	
Carding room	8.6
Weaving and spinning room	4.5

(J. J. Bloomfield, *Heating and Ventilating*, July 1934.)

HEATING & VENTILATING INDEX

District Heating. 621.312

District Steam Heating. B. M. Conaty. 2 pp., 2 illus. Dealing with operating companies and rates : *The Steam Engineer*, June 1934.

Noise. 534

Sound Control in Air Conditioning. Vern O. Knudsen. 4½ pp., 6 illus. Dealing with standardisation of noise units, reducing noise through ducts and how temperature and humidity affect acoustics : *Heating, Piping and Air Conditioning*, June 1934.

Heat Pump. 621.536

Heating and Air Conditioning Buildings with the Reversed Refrigeration Cycle. C. F. Mowrey. 3½ pp., 1 illus. Describing how a gas-engine-driven compressor (or heat pump) can be used to heat buildings by the reversed refrigeration cycle : *Heating, Piping and Air Conditioning*, June and July, 1934.

Insulation. 536.2

Insulating Value of Bright Metallic Surfaces. F. B. Rowley. 3½ pp., 2 illus. Dealing with the effect of bright metallic surfaces on the heat transmission coefficients : *Heating, Piping and Air Conditioning*, June 1934.

Heat Transfer. 536.2

Heat Transfer from Direct and Extended Surfaces with Forced Air Circulation. G. L. Tuve and C. A. McKeeman. 7 pp., 8 illus. Dealing with heat transfer equations, tests and correlation with previous investigations : *Heating, Piping and Air Conditioning*, June 1934.

Steam Heating. 697.52

Chauffage a Vapeur a Basse Pression. B. Guillot. 2¼ pp., 7 illus. Describing low-pressure steam heating and apparatus : *La Couverture-Plomberie*, June 1934.

Hot Water Heating. 697.4

Radiation. Leslie Rayner. 3½ pp., 5 illus. Dealing with circulating head for pipe sizing : *The Plumber*, July 2nd, 1934.

Insulation. 536.2

Insulated Construction. C. W. Glover. 9 pp., 8 illus. Dealing with economics of insulation, sound and measurement, thermal insulation, vibration and damping devices : *The Architects' Journal*. July 5th, 1934.

Steam. 621.101.1

Superheated Steam for Small Plants. Chas. F. Wade. 1 pp. Dealing with use of superheated steam : *The Steam Engineer*, July 1934

District Heating. 621.312

Direct Steam Heating. B. M. Conaty. 3 pp., 4 illus. Dealing with standard types of underground steam line construction : *The Steam Engineer*, July 1934.

Dust. 628.511

There is no Dustless Air. C. Gordon Vokes. 3 pp., 3 illus. Dealing with filtration efficiency, preventing wear and tear, dust recovery and panel units : *The Parthenon*, July 1934.

Heating. 621.182

Automatic Heating Systems. George H. Hirons. Dealing with fuels, calorific value and fuel costs : *Heating and Ventilating Engineer*, July 1934.

Drying. 634-9

Principles of Drying. C. W. Ulett. 2¾ pp., 1 illus. Dealing with measuring instruments and drying terminology : *Heating and Ventilating Engineer*, July 1934.

Ventilation. 621.53, 622.416

Students' Textbook of Heating and Ventilation. Norman Wignall. 5½ pp., 5 illus. Dealing with design of air ducts and calculations : *Heating and Ventilating Engineer*, July 1934.

Air Conditioning. 697.96

Dry Bulb vs. Effective Temperature. A. E. Beals. 3¾ pp., 2 illus. Discussing the value of dry-bulb temperature measurement in relation to effective temperature : *Heating, Piping and Air Conditioning*. July 1934.

Dust and Fume Removal. 628.511

Criteria for Industrial Exhaust Systems. J. J. Bloomfield. 5½ pp., 6 illus. Dealing with sampling and analysis of dusts, fumes, gases and vapours and application of test methods : *Heating, Piping and Air Conditioning*, July 1934.

Libraries. 727.8

Air Conditioning of Libraries. 2¾ pp., 2 illus. Dealing with prevention of damage by sulphur dioxide and importance of temperature and humidity : *Heating, Piping and Air Conditioning*, July 1934.

SOME PROBLEMS OF BOILER WATER TREATMENT WITH PARTICULAR REFERENCE TO COLLOIDAL CONDITIONING

By GEORGE S. IRVING, A.M.I.Chem.E.

PAPER READ BEFORE JOINT MEETING OF THE SOCIETY OF CHEMICAL INDUSTRY AND THE INSTITUTE OF CHEMISTRY

CARDIFF, MARCH 8th, 1934

Introduction.

Steam is not being economically generated if, after it leaves a boiler, it causes troubles in other parts of the plant, necessitating periodical expenditure of time and money. Two examples will suffice. A small amount of deposit on turbine blades can have a serious effect on the output power of a turbine, whilst a very small amount of alkaline spray in steam pipes leading to dye houses, etc., may result in serious and expensive troubles. It is thought by some that to supply boilers with a water that has been " softened " is all that is necessary ; but the " conditioning " of the boiler feed water only begins with the water entering the boiler. In other words, it is the *internal* conditions which have to be considered, and in that sense all treatments can be considered as *internal*. In some cases a softener may be desirable, depending on conditions and where water for process work is involved.

Softened water may have a low residual hardness, but it is still necessary to take into account, and make provision for, the excess alkalinity and the other soluble sodium salts, together with the residual hardness. Without such control, foaming can easily occur, or there may be danger of caustic embrittlement if the caustic alkalinity of the boiler water reaches too high a figure, coupled with a deficiency of sulphates. Serious corrosion may result from under-softening of a water. For example, a base exchange softener on a water having a high temporary hardness may be ideal for softening the water for use in process work ; but such water of zero hardness if fed to boilers contains free bicarbonate of soda, and rapidly develops in the boilers an excessive alkalinity, causing trouble in a variety

---

Extract reprinted from the Journal of the Society of Chemical Industry, July 20 and July 27, 1934, Vol. LIII, No. 29 and 30, "Chemistry and Industry," pp. 633-638 and 652-656.

of directions. Such a water is not suitable for boiler feed purposes. This shows that the removal of hardness from a boiler feed water is not the beginning and end of its treatment.

It is not proposed to deal with the substances which are well known to chemists as causing scale and corrosion in boilers, but to make reference to one or two unusual types of boiler feed water and scales.

At a certain colliery a pit water was used when short of surface water. (All analytical figures mentioned are in parts of $CaCO_3$ per 100,000 except where otherwise stated.)

Pit water :

Temporary hardness	16.5
Permanent hardness	139.8
Total hardness	156.3

The boilers are Lancashire boilers—60 lb. pressure, evaporating 4,000 gal. each daily, emptied every 2-3 months. No condensate. The pit water has often been used for months together, and probably constitutes one of the hardest boiler feed waters in this country. The water is treated internally by a special colloidal treatment to which reference is made later, with the result that the heating surfaces are being kept free from hard scale formation. The permanent hardness in the water is due to chlorides and sulphates of calcium and magnesium.

The feed water for another colliery has the following composition :

Temporary hardness	15.0	parts	per 100,000	as	$CaCO_3$
Permanent hardness	27.2	,,	,,	,,	,,
Total hardness	42.2	,,	,,	,	,,
Total alkalinity	15.0	,,	,,	,,	,,
Chlorides	6.5	,,	,,	,,	Cl
Sulphates	47.4	,,	,,	,,	SO_4
Reaction	Alkaline				
Total mineral solids	78.9	,,	,,	,,	,,

During very rainy weather, the total hardness would decrease, and a sample taken when the hardness was 25.0 gave the following results :—

Sulphate of iron, etc.	0.6
,, ammonia	5.05
Chalk	8.0
Sulphate of lime	8.4
,, magnesia	11.8
Sodium sulphate	3.37
,, chloride	5.9
,, silicate	2.64
,, nitrate	0.24
Total mineral solids	46.00
Total hardness	24.5

An average of 30 samples taken from 1930 to the end of 1933 showed an average total hardness of 31.5 parts per 100,000, the lowest being 20.8, the highest 62.1. Lancashire boilers are in use at 90-lb. pressure normally, emptied every 6 weeks, but during the drought of 1933, owing to shortage of water, they were often run for twice that length of time. When the density of the water in the boilers exceeds 1/32nd (approximately 5° Twaddel at 60° F.), a special form of scale deposits, particularly on the bottom of the shell of the boiler, and at times reaches a thickness of 4 in. 100 parts of the powdered scale treated with 100 parts of boiling water: filtering, crystallizing, and re-crystallizing, gave crystals of the following composition.

	Per cent.
Moisture	4.64
Sodium sulphate (crystalline)	92.68
Magnesium sulphate (crystalline) ..	1.30
Sodium chloride	0.18
„ carbonate	0.37
	99.17

Some long needle crystals were also found—

	Per cent.
H_2O	56.5
MgO	11.59
SO_3	21.6

A sample of scale examined December 23rd, 1931, gave the following results :—

Very hard, 1¾ in. thick, black in colour, contained a small amount of organic matter, no oil, trace of chalk, large amount of sulphate of lime, very small amount of oxides of iron and aluminium compounds, small amount silica. This large, thick piece of scale, had a moist appearance, and fused at a black heat.

	Per cent.
Amount soluble in water	55.5
Volatile at 100° C.	4.2
„ 150° C.	5.0
Organic matter	4.1
Total alkalinity of the scale as a whole in terms of sodium carbonate which was present in the water-soluble portion ..	0.7
Portion insoluble in water at 90° C. ..	44.5

Of the soluble 55.5 per cent. there was :—

	Per cent.
Sodium carbonate	0.7
„ sulphate	31.1
Salt	5.6
Magnesium sulphate	10.8
Calcium sulphate	1.9
	50.1
Volatile at 150° C. (which will consist of water of crystallization)	5.0
Not determined	0.4
	55.5

Of the insoluble 44.5 per cent. there was :—

	Per cent.
Silica	0.23
Oxides of iron and aluminium	0.8
Sulphate of lime	38.25
Magnesium oxide	2.2
	41.48
Organic matter	3.02
	44.50

It will be seen that the two principal ingredients are calcium sulphate 40.15 per cent., and sodium sulphate, 31.1 per cent. This scale is of interest, because roughly half of it is soluble in water.

Investigations carried out a few years ago on the solubility of gypsum, by Dr. Hall, Carnegie Institute of Technology, Pittsburgh, U.S.A., make reference to the solubility of gypsum in the presence of sodium sulphate, and indicated that there was a possibility of such a scale forming. His work was carried out under laboratory conditions. He states that sodium sulphate increases the solubility after it has reached a certain minimum, and continues to increase with increasing concentration of the sodium sulphate until "a limit is reached when equilibrium becomes established in the solution and Glauberite, $Na_2SO_4.CaSO_4$, comes out as a solid phase."

The solubilities of calcium sulphate and calcium carbonate at temperatures between 182° C. and 316° C. have been determined by F. G. Straub, *Industrial and Engineering Chemistry*, page 914, August, 1932. Straub states that the solubility of calcium carbonate decreases with increase in temperature, which is against the theory that calcium carbonate has a positive solubility curve.

The decomposition of soda ash in dilute solution has also been studied between temperatures from 147° C. to 243° C., by F. G. Straub and R. F. Larson, *Industrial and Engineering Chemistry*, December, 1932, page 1416. Decomposition is as follows :

Temperature	*Soda ash decomposed, per cent.*
189° C.	65
208° C.	73
243° C.	80

This is of importance in connection with caustic embrittlement.

At a colliery in Lancashire a sample of scale (from a Lancashire boiler working on pit water) having a thickness of 1¼ in. to 2½ in. and very hard, was found to be soluble to the extent of 61.6 per cent. when 10 g. of the scale were treated with 100 g. of boiling water. The soluble portion consisted chiefly of magnesium sulphate with a certain amount of sodium sulphate. The insoluble part of the scale consisted of sulphate of lime and chalk, about equal parts, with small amounts of organic matter, oxides of iron, etc. Magnesium sulphate crystals separated easily from the soluble portion. This scale is probably of polyhalite composition.

Glauberite, $Na_2SO_4.CaSO_4$ shows approximately equal parts of gypsum as compared with sodium sulphate—

Polyhalite :	*Per cent.*
$CaSO_4$	47.8
$MgSO_4$	21.1
Na_2SO_4	24.8
H_2O	6.3

During times of drought, should engineers find it necessary, owing to water shortage, to work boilers to a decidedly higher density than that usually obtaining, it is recommended that they obtain advice from a specialist on the subject as to what may happen when the boiler feed water becomes dense. In this way they will avoid bulging of furnaces or at least prevent deposition of scales, such as those referred to above.

Heat Conductivity of Boiler Scale.

The most recent researches are those carried out by E. P. Partridge, the results of which are given in a bulletin published by the University of Michigan, 1932. "The heat conductivity coefficient (*K*) of dense non-porous scales, of the calcium sulphate type varies between 1 and 2. For dense chalky scales containing a fair amount of sulphate of lime, the figure is approximately 0.8 to 1.3. The physical structure of the scale has a profound effect on its conductivity ; but the chemical composition has but little effect except as it affects the structure. For more porous scales the value of *K* can be taken as 0.5 and for very porous scales of the silicate type as low as 0.05." The lower the value of K the greater the resistance the scale offers to heat. K = B.T.U. per sq. ft., per hour, per foot thickness, per 1° F. temperature difference.

In the past it was common to accept Professor Rankine's figures (published many years ago) for the loss of fuel due to certain thicknesses of scale $\frac{1}{16}$ in. = 16 per cent. loss, $\frac{1}{4}$ in. = 50 per cent. loss. Investigations of E. P. Partridge would indicate that the fuel loss for a *dense* type of scale will probably not amount to more than 3 per cent. for a scale $\frac{1}{12}$ in. thick. This means a loss of 9 per cent. on a scale $\frac{1}{4}$ in. thick. Note, however, that the conductivity of boiler scales decreases with increase in porosity, and very porous scales may have a heat conductivity of only one-twentieth of the average of non-porous scales. It will be seen that a figure of 9 per cent. loss for a scale $\frac{1}{4}$ in. thick is a minimum loss for the denser types of scale, and the more porous the scale, the greater will be the loss of fuel. This should help to reconcile the conflicting views of engineers on the matter, some of whom have stated that from actual tests in boilers under their control the loss of fuel between the boiler being clean and dirty (say $\frac{1}{8}$ in. scale generally, Lancashire boiler) was not more than 5 per cent., whereas according to Professor Rankine it should be about 30 per cent. Other engineers with a more porous type of scale in the boilers, particularly if traces of oil were entering with the feed water, have found a marked difference in the fuel consumption between the boiler being clean and dirty. It is important to keep scale from forming on the surfaces of plates and tubes, as any scale means loss of fuel, which may be small or large, depending on the type of scale.

Formation of Scale in Boilers.

It is not proposed to deal in full with the various theories of scale formation. An excellent article on the subject is given in the *Engineer* for June 21st, 1929. The bubble theory is there advanced and, bearing in mind the work of Hall, it will be seen that substances having a negative slope for their solubility curve will be deposited at the heating surfaces, particularly where bubbles of steam are formed. In the *Engineer* reference is made to colloidal treatment of water thus :—" The authors found that several of them (colloidal solutions) were adsorbed on the calcium sulphate crystals after the latter were formed on the metal, and strongly modified the physical characteristics of the scale. In some cases, indeed, the scale becomes so weak as to flake off the metal surfaces under the action of convection currents. It appears probable, therefore, that some colloids might be beneficial in minimising scale troubles." Knowing the type of scale that would be likely to be deposited one can calculate the maximum thickness that would be permissible for a given type of boiler at a given pressure.

Velocity of Water in Boilers (Circulation of Boilers).

It is well known that the velocity of water in different parts of water tube boilers is decidedly higher than in the case of boilers of the Cornish or Lancashire type. Actual measurements have been carried out on water tube boilers by Sulzer Bros., London, and also by the Stirling Boiler Co. For water tube boilers figures are from 2 to 10 ft. per sec.; in a Stirling boiler from 6 to 10 ft. per sec. Following on correspondence with English boiler-makers it appears that there is no record of tests of velocity of water in different parts of Lancashire boilers.

Messrs. Sulzer Bros., London, in a private communication state :—

"On theoretical grounds there is reason to believe that the average velocity of water in a Lancashire boiler at the narrowest part between the flue tubes and at a distance of about one-third the length of the boiler from the back end, amounts to about 0.3 to 0.5 metres per sec., and that the mean horizontal velocity of the water above the crown of the flue tubes is about 0.050/0.2 metres per sec. These figures may be wide of the mark, as many assumptions have to be made in connection with the calculations."

The velocity of water in a boiler has an important bearing on the question of circulation, scale formation, and the points at which most sludge will be deposited. Velocity tends to hinder scale formation. Very often, however, the zone of greatest velocity is also the zone of greatest heat, and it is at this point that most of the calcium sulphate scale is deposited if the water is not correctly conditioned.

Foaming and Priming.

A number of theories have been advanced in the past to account for the foaming of waters in boilers and evaporators. These theories embrace such ideas as the introduction or formation of soapy substances in the water; alteration of the surface tension, particularly at the surface of the water; or an increase in concentration of alkaline materials, and it is interesting to note that one school of thought claimed that the surface tension decreased and caused foaming, whilst another school held the opposite view. All were agreed, however, that suspended matter plus soluble salts in a boiler increased the risk of foaming.

No real attempt to investigate the fundamentals of the problem was made prior to 1923. Professor C. W. Foulk of Ohio State University has given much time to investigations into the causes of foaming. His work has not, in the author's opinion, received that attention in this country which it merits, and in what follows I have given a summary of Foulk's work on this problem as given in the following papers, using his own words as far as possible :

C. W. Foulk, " A Theory of Liquid Film Formation," *Industrial and Engineering Chemistry*, September 1929.

C. W. Foulk and J. N. Miller, " Experimental Evidence in Support of the Balanced Layer Theory of Liquid Film Formation." *Industrial and Engineering Chemistry*, November 1931.

C. W. Foulk, " Foaming and Priming of Boiler Water," *Transactions of the American Society of Mechanical Engineers*, November 30th, 1931.

C. W. Foulk and V. L. Hansley, " Solid Matter in Boiler-water Foaming. Experiments at Atmospheric Pressure." *Industrial and Engineering Chemistry*, March 1932.

C. W. Foulk, " Effect of Suspended Solids." American Society of Mechanical Engineers, June 1933. (Experiments at boiler pressures.)

Liquid films are always formed by the approach to each other, usually with an extension of area, of two already formed liquid surfaces. In the case of solutions the mechanical force acting to bring the surfaces together, meets with resistance when the layer of liquid between the surfaces becomes very thin, with the result that a film is produced. In the case of pure liquids, no such resistance is encountered and consequently the two surfaces merge and vanish. The reason for the counter force in the case of solutions is the difference in concentration between the surface layer of the liquid and the mass of the liquid. Solute either concentrates in the surface or recedes from the surface. In either case this movement of matter takes place against diffusion, and it will, therefore, require work to restore the equality of concentration ; in other words, thin surface layers will resist a force to mix them. This theory harmonises the puzzling facts that both positively and negatively adsorbed dissolved matter causes foam in liquids, and explains why pure liquids do not foam.

The statement is also made that film formation and film stability are separate questions which in the past have often been confused.

(1) Pure liquids do not foam, and there is no record of a pure liquid foaming. No one has yet given an explanation as to why this is so. It is a matter of experience.

(2) Some impurities must be present in the liquid to make it foam which substances may be either molecularly dissolved or colloidally dispersed in a liquid. Nearly all substances induce foaming, so that the nature of the added substance has little effect qualitatively. Quantitatively there are great differences. A few thousandths of 1 per cent. of some substances will give more foam than several per cents. of others, and there is a great difference in the stability of the different foams.

(3) Qualitatively speaking, it does not matter whether the added substance is positively adsorbed—that is, more concentrated in the

surface than in the interior of the liquid—or negatively adsorbed, i.e., less concentration in the surface. In both cases foams can be produced. Since positively adsorbed substances lower the surface tension, and negatively adsorbed substances raise it, there is no correlation between foaminess and surface tension.

(4) Certain substances have the power of destroying foam and of preventing the formation of it. Some of these anti-foams may destroy or inhibit the foams produced by positively- or negatively-adsorbed substances. Castor oil will destroy the foam, produced by positively-adsorbed saponin, and also that produced by sodium sulphate—negatively adsorbed. Some anti-foams, like the foam producers, are at times effective in concentrations of only a few thousandths of 1 per cent.

In the laboratory at the Ohio University an experiment has been carried out in which two bubbles are forced to touch under the surface of a liquid. In a pure liquid they emerge at once and rise to the surface as a single bubble. In a solution they will flatten against each other, or roll over each other, but will not coalesce. This experiment has the advantage of eliminating the effect of the air on the stability of the film.

Foams are of importance in everyday life in industry. There is the evaporation and distillation of liquids where foams are a nuisance. They are of great advantage, however, in the laundry, in textile works, and in the separation of ores by flotation. When a bubble rises to the surface of a pure liquid, the liquid drains from between the inside and outside surfaces of the bubble until equilibrium is reached, that is until the two surfaces cease their movement towards each other. There is no pause in a pure liquid in the approach to each other of the two surfaces and, consequently, no bubble forms on the surface.

Using a dynamic foam meter it will be found that with a pure liquid there would only be a trace or no foam at all. As a solution is made stronger and stronger, the bubbles become gradually less in size, and there is a point at which they cease to coalesce and the liquid takes on a white appearance, due to the mass of tiny air bubbles in it. The foam grows thicker on the surface as the concentration of salt increases. Small bubbles merge together in pure liquids to form larger ones, that is, no permanent liquid film is formed between the interior surface of two approaching bubbles. Soluble substances cause the bubbles to roll past each other without merging. The foaming of the substances of the negatively adsorbed sodium sulphate is stopped by the addition of a little soap, which is positively adsorbed.

In the foam meter using molar solutions the following give the order starting with the least foam : sodium thiocyanate, calcium chloride, salt, soda ash, sodium sulphate, magnesium sulphate, the latter being twice as active as the first substance. All these are negatively adsorbed except the first one.

It is known that all solutions do not foam or form films, as, for example, strong solutions of cane sugar and solutions of H_2SO_4 at certain concentrations.

Dynamic surface tension means a measurement made on a surface within a small fraction of a second after the formation or extension of the surface. Static surface tension on the other hand, is that of an old surface, and in the case of pure liquids, the two measurements are the same. A freshly-formed surface that has been in existence for only a fraction of a second will be different from that of an old surface. Sugar solutions foam at low concentrations. Contrary to most organic substances, cane sugar is slightly negatively adsorbed. It follows that there should be certain mixtures of positively and negatively adsorbed substances that do not foam as they will cancel each other by producing equality of concentration between surface and mass.

Example.—Sodium sulphate and alcohol.
„ „ „ soap.
„ „ „ castor oil.
„ „ „ sodium thiocyanate.

The following shows a non-foaming mixture :—100 c.c. of sodium thiocyanate plus 32.5 c.c. of sodium sulphate, both in molar solution.

In connection with these, the static and dynamic surface tensions are the same. It is when these two differ that foaming occurs, but an increase or decrease of surface tension as compared with water is not the explanation as to why foaming occurs. In other words, surface tension has nothing to do with it. Sodium sulphate causes more film formation than salt for equal molar concentrations, but for equal concentration the sodium effect is almost identical, but this does not hold in the case of sodium thiocyanate.

It should be made clear that the film stability is quite a different thing from film formation. It may be that some films—example, those made from soap—are unusually tough accompanying a high degree of positive adsorption.

Particle Size of Suspended Solids.

It is generally agreed that suspended matter does play an important part in connection with foaming, and that the finer the particles up to a point, the more they help foaming. Certain substances, such as caustic soda, soda ash, phosphates, salt, and magnesium sulphate have an influence on particle size. Niehaus, after carrying out elaborate tests states at the end of his paper, that soluble phosphates should be kept below 1.5 to 2 parts per 100,000 ; that is a very low concentration.

Solid Matter in Boiler Water.

Joseph and Hancock (*J. Soc. Chem. Ind.*, Vol. 46, p. 315 T, 1927; also Vol. 49, p. 369 T, 1930) carried out experiments at 150 lb. pressure in a steel boiler, and they came to the conclusion that solid matter had no effect on the amount of water thrown into the steam. Do not confuse that, however, with the soluble substances dissolved. Another experimenter commenced his tests with distilled water and salt solutions, and it was found that distilled water threw more water into the steam space and it decreased regularly as the concentration in the water increased. Sodium sulphate, soda ash and caustic soda gave less water in the steam than salt, quite contrary to the popular belief.

Scores of experiments were made, and the point proved beyond doubt. Finally, it was found that there was no difference in the results—carrying out tests at 150 lb. pressure to 12 lb. pressure, or even atmospheric. An explanation was found. Using a Pyrex glass boiler the waves were highest for distilled water, and as the amount of salt increased the waves flattened out and not so many crests hit the steam outlet. With distilled water, the bubbles were very much larger than with the salt solutions. The steam bubbles, as proved by using a glass boiler with cinematograph films, showed very much smaller bubbles in the salt than other solutions.

Experience is now on record where water tube boilers have tolerated an enormous concentration of dissolved matter, as, for example, in the nitrate industry in South America.

From the above, it will be seen how easy it would be, especially if one had no special knowledge of the subject, to come to the conclusion from experiments with distilled water that the theory of increased concentration of salts causes foaming is all wrong because he had data to the contrary. It just goes to show the enormous complexity of the problem. In distilled water big bubbles are formed, but they do not set up a stable foam. In the case of salt solutions with or without suspended matter, foams are produced.

Effect of Suspended Solids.

Surface viscosity plays a part. Different kinds of solid matter exhibit greatly different effects in stabilising the foams of boiler salt solutions. Finely-ground flint has no stabilising effect, but it is considered that the greater the tendency of the solids to float on the surface, the more they are apt to stabilise foam, and it would appear that the floatability is inversely proportional to the tendency of the solid to be wet by the solution. The flint is instantly wet and instantly sinks.

Absorbed Oil in Boiler Scale.

This has a very high stabilising effect. If you extract the oil from the boiler scale, it loses nearly all its foam-producing, stabilising properties, or if you burn the scale and destroy the oil and shake it up with water, the residue has very little effect on the foam.

Chalk, boiler scale, and the like, lose their foam-stabilising properties in from 3 to 11 hours at atmospheric pressure, but at a very much quicker rate in high-pressure boilers.

The preponderance of evidence is on the side of the opinion that suspended solids in the boiler water increase the moisture in the steam, but bear in mind that in a few cases that has not been the case.

Alkalinity and Foaming.

A special investigation was carried out by the New York Steam Corporation, and they came to the conclusion that caustic alkalinity assists foaming for a critical value for a given type of boiler, the value in question was 22 to 25 parts per 100,000 hydroxyl, and was independent of the length of time the boilers had been working. It should be mentioned that in these particular experiments there was no organic matter present.

Organic Matter.

Certain kinds of organic matter, particularly proteinous matter, assists foaming, as with alkalis it tends to form soaps. There is, however, a difference of opinion amongst investigators as to whether the organic matter must be in solution, or in suspension.

This concludes the references to the work of Professor C. W. Foulk.

Practical Means of Preventing and Reducing Foaming.

Keep down the concentration of suspended matter, and soluble salts. For any particular boiler there is a definite relationship between these two, and should foaming occur, gauge glass samples should be immediately taken and examined for these two items. The estimation of the chlorides in gauge glass samples provides a quick and ready means. As already mentioned, however, each case of foaming should be studied to determine what is the limit of concentration of chlorides or suspended matter, before foaming commences.

A much more important figure than the salt is the total alkalinity, and if boilers give trouble with foaming, it is not advisable for the total alkalinity to exceed 100 parts per 100,000 in terms of $CaCO_3$ From a mechanical point of view it is recommended :

(*a*) That the level of water in the gauge glasses is kept to half glass, or just below, during all working hours.

(*b*) Avoid sudden opening of large steam valves.

(*c*) Use blow-off valve on boiler at regular intervals, say, once every 8 hours.

(*d*) Keep oil out of boilers.

The author never ceases to wonder why managers and engineers in factories where live steam is used in process work (such as in dye-houses, breweries, or other industries where the steam must be pure), do not fit large external steam separators. No one would dream to-day of using electrical machinery not provided with fuses as a safety precaution. Similarly, where live steam is used in process work, adequate precautions should be taken. During times of drought, feed waters are liable to increase greatly in hardness, and foaming may occur owing to the greatly increased amount of suspended matter in the boilers.

Corrosion.

There are several theories known as the acid, colloidal, electro-chemical, and differential-aeration theories, the latter being the most recent. Not one of these theories by itself will explain all types of corrosion found in boilers, economisers or the like. Very little appears to have been added to the subject following on the work of U. R. Evans (on the corrosion of iron and steel), many of whose papers have been published in the *Journal of the Society of Chemical Industry*.

From the practical standpoint, the acid theory indicates that if such substances are neutralised by suitable alkalis, corrosion should cease. The electro-chemical theory indicates a variety of means of dealing with corrosion, whilst the differential-aeration theory indicates the advisability of avoiding marked differences in the aeration of the water in contact with the metal. If corrosion is found going on underneath boiler scale, the latter theory indicates the importance of keeping the boiler free from such scale. When boilers have been cleaned, it is important that any parts of the metal which show corrosion are well wire-brushed to remove the products of the corrosion, since the metal is anodic to its oxides.

All four theories are electro-chemical at base. It is known that corrosion by acids is greatly accelerated by the presence of oxygen. It can also be said that all four theories stress the active part played by oxygen. This subject is dealt with at some length in a paper entitled "Corrosion with Reference to Boilers," by T. Millican, *Transactions of the North-East Coast Institute of Engineers and Shipbuilders*, March 20th, 1931, where the various theories are set forth, and there is a full discussion on the paper included.

Some engineers and chemists are under the impression that if the water in the boiler is decidedly alkaline, especially if there is a certain amount of caustic alkalinity present, corrosion cannot go on. Exceptions try the rule; cases are known of Lancashire boilers which have been treated internally with a mixture of caustic soda and soda ash, where the total alkalinity in parts per 100,000 at the end of 2 months reached 150 parts. While the boilers were free from hard deposit, active corrosion was taking place, despite the fact that from the time the boiler was filled, and had worked a few days, the alkalinity was 15 parts per 100,000, a portion of which was caustic alkalinity. The difficulty was overcome by the use of oxygen absorbing substances, incorporated in an internal treatment, and it was found that the boilers could be protected from corrosion, and the alkalinity not allowed to rise over 70 parts.

Colloidal Conditioning.

It is impossible, in the course of this paper, to deal even briefly with all the forms of treatment which have been put forward in the past. These treatments include the use of chemicals such as soda and lime, boiler composition, softening plants, electrical systems, etc. Colloidal substances are coming to the fore in industry to-day, and meriting earnest consideration. It is necessary, however, to differentiate between a colloid which is suitable for water conditioning and those which are not.

Colloids can exist in two states—in sol or solution form, or as a gel—a gel resulting from the coagulation of a colloid formerly in the sol state. Examples of gel formation are the solidification of the white of an egg upon boiling and the clotting of blood when treating a cut with alum. The coagulation of a colloid is an electrical phenomenon, it being found that the majority of colloids carry an electric charge on the particles when these are dispersed in sol form.

A colloidal solution is made up of two phases, the fluid medium being known as the dispersion medium, and the suspended particles (which may be either liquid or solid) as the disperse phase. If, by any means, the electric charge on the particles of the disperse phase is neutralised, coagulation occurs and the colloid is precipitated in the form of a gel. This electrical precipitation is an essential feature of a colloid suitable for water treatment purposes. The neutralisation of the charge may be effected by the scale salts present in a boiler water. When mutual precipitation occurs both the colloid and the scale salts, such as calcium sulphate, magnesium carbonate, etc., are removed from solution ; also any impurities in suspension.

In the process of precipitation a colloidal film or sheath is formed around each particle of suspended matter which may be present in the water. Under boiler conditions this suspended matter might take the form of particles of scale salts, or dirt entering the boiler with the feed, etc.

Colloidal conditioning can be divided into two types :—

(*a*) This relies solely on the use of substances which act as "protective colloids." The action is entirely physical and use is made of such substances as starch, glue, Irish moss, and the like.

(*b*) Organic substances which form colloidal gels with lime salts. Into this class fall alginates. These not only act as " protective colloids " (particularly if used in sufficient amounts), but the particles of gel of calcium alginate, in the boiler, absorb a suitable amount of water and thus cannot bake on to the boiler plates. For this reason they are superior to inorganic colloids.

It is necessary first to form a neutral alginate, so as to make it soluble in water, to which can be added many substances valuable for the treatment of boiler feed waters, such as other colloids, alkalies, etc. A whole range of formulæ can thus be set out for the treatment of different kinds of waters in different types of plants.

It cannot be too strongly emphasised that each case of boiler feed water treatment should be investigated in respect of its chemical and engineering features, and a formula devised to suit those conditions, thus giving individual treatment to each case. There is no one formula that is good for all boiler plants. As testimony in this direction, reference is made to an article in *Power*, mid-December 1933, issue, page 687, entitled " Standard Ship Boiler Compound." It consists of anhydrous di-sodium phosphate 47 per cent., soda ash, 44 per cent., corn starch 9 per cent.

It stated that in a discussion that followed, " that practically every speaker pointed to the danger that operators of plants on land might attempt to use the proposed new navy compound," and that, " it would be worse than useless to attempt to apply the navy formula to any other boiler than those of the ships of the Fleet, even the merchant marine could not, with safety, use this formula."

It is important that the charge on a colloid for water treatment should be negative, so that precipitation is brought about by positively charged metallic ions and sols. If a colloidal sol of ferric hydroxide is mixed with a water treatment colloid having a negative charge, both colloids are precipitated in a gel state. The colloidal theory of corrosion put forward by Dr. Newton Friend, states that colloidal ferric hydroxide acts catalygically in the oxidation of iron, and that any agent which will remove this ferric hydroxide from solution will tend to inhibit the corrosion.

The author wishes to express his thanks to the Directors of Feedwater Specialists Co. for permission to publish the results of some of his work, which was carried out in their research laboratories at Liverpool.

GAS AND COKE-FIRED BOILERS FOR CENTRAL HEATING AND DOMESTIC WATER HEATING

By S. ADAMS, (Associate Member)

PAPER READ BEFORE THE INSTITUTION OF ENGINEERS-IN-CHARGE
LONDON, DECEMBER 13th, 1933

THE question of central heating has been tackled in various ways, and many developments have resulted. Central-heating plants, high and low temperature radiant panels and air-conditioning schemes have been designed, and the use of one or of a combination of these systems has resulted in a large number of highly efficient heating and ventilating installations, which add greatly to the comfort and convenience of th eoccupants of the buildings in which they are installed.

Central Heating.

It must be realised that ventilation and heating are closely allied subjects ; in fact, the two are strictly interdependent, and any change in a heating system is liable to affect the ventilation. In illustration of this fact it might be mentioned that there was recently a tendency to eliminate some or all of the chimney flues in buildings in which central heating plant had been installed. Such arrangements obviously affect the air change, and unless mechanical ventilation is applied, the resulting air movement is very much restricted, and the conditions are far from ideal. Such flueless buildings seemed in the past few years to meet with the approval of some of the ruling bodies, but one cannot disguise the fact that chimney flues or ventilating ducts provide that continuous natural ventilation and air movement which is so essential to comfort and hygiene. This fact, however, is now becoming recognised, and the present tendency is to attach greater importance to the construction of flues or ventilating ducts irrespective of the method of heating applied.

Building Considerations.

In this connection it must be realised that a modern heating scheme at its best is not just something added to a building, but is rather an essential part of its construction. For this reason the method of heating which is to be adopted should be considered at an early stage in the planning, and if full advantage is to be taken of the latest technical developments, a detailed heating scheme should be worked out on a quantitative basis. The primary considerations in building construction are, of course, strength, utility and resistance to atmospheric effects, but there are others which, as research has shown, should also be taken into account if the best and most economical heating conditions are to be obtained. One of the most important of these is conduction of heat, for while it is essential to generate heat in the right quantities and to apply it in the right form, it is equally necessary to conserve as far as possible the heat liberated in the building. To some extent heat losses are inevitable on account of air change, but the further heat loss which takes place by conduction through windows, walls, ceilings and floors cannot be said to serve any useful purpose, and this should therefore be reduced to a minimum. With present-day buildings this loss has indeed been reduced, perhaps incidentally, by cavity walls, hollow floors and Mansard roofs of hollow blocks, etc., but apparently very little provision is made for insulation in most cases. In special buildings, such as Turkish baths, drying rooms and the like, where high temperatures prevail, heat loss by conduction is a more serious matter which must of necessity receive careful consideration.

Heat losses by conduction can now be calculated with some exactitude, and standard figures are available for the heat transmission per unit temperature difference through walls of different thicknesses, windows, floors and roofs of different types. These figures indicate that the heat loss by conduction may be of the order of 50 per cent. or more of the total loss, so that the question of insulation may well be worth looking into.

Comfort Conditions.

Since the primary object of central heating is to produce the most comfortable conditions for the occupants of the building, it is worth examining the controlling factors.

The essential point is that the human body is comfortable when it is losing heat at approximately a standard rate ; that is to say, that when a person is suffering from cold, it is not because he is not heated—Nature attends to that from the inside—but because he is not sufficiently insulated. This insulation consists of his clothes and of the surrounding conditions of the apartment ; heating systems are not required so much to convey heat to the occupants of the apartment, as to prevent excessive loss of heat generated by the human body. A leading authority states that the normal heat loss from a person following a sedentary occupation in a closed room at a temperature of 60° F., excluding loss by evaporation, is 195 B.T.U. per hour by radiation and 138 by convection, a total of 333 B.T.U. per hour. To prevent this heat loss from becoming excessive, it is necessary to maintain the environment at a certain temperature, and this is the first requirement for comfort conditions.

The second requirement is concerned with ventilation, the effect of which may be considered in terms of the relative humidity, which for comfort conditions should be maintained in the region of 60 per cent. This figure is liable to be exceeded when air movement is insufficient or when rooms are excessively crowded, but the relative humidity figure is also liable to vary according to the external atmospheric conditions, which can only be compensated if some form of air-conditioning plant is employed. Heat can be transferred to the body by two distinct agencies, radiation and convection. Radiation implies the emission of heat from suitably-placed hot surfaces and its reception directly by the human body, whereas convection implies that the air of the apartment is first warmed and forms an intermediate heating agent.

The available heating mechanisms make use of these two forms of heat in different proportions ; thus, for instance, hot panels produce a high proportion of radiant heat, whereas air warming schemes rely almost exclusively on convection, and, in fact, the normal hot-water radiator is inaptly named, because it also produces a very high proportion of convective heat. The use of radiant heating has been considerably favoured recently, and various advantages are claimed for it. Comfort conditions can be obtained more rapidly with appreciably lower air temperatures when radiant heat panels are used than with ordinary radiator heating. It is also claimed that the method is intrinsically more economical.

Methods of Heat Application.

The process of central heating may be said to take place in two stages : (1) the generation of heat in some centrally situated boiler-house, and (2) the distribution of this heat to different parts of the building, and its liberation in the various apartments. The term, however, is now beginning to be used in cases which do not conform with this definition, as, for instance, with electric or gas-heated panels. In these cases there is no central generation of heat, but, on the other hand, central control can still be applied, so that it may be considered legitimate to include such methods of heating under the more general term.

Before considering the generation of heat, it will be well to discuss in some detail the alternative methods of heat distribution and liberation. The three media by means of which this distribution is normally carried out are water, steam and air, the former still being by far the most popular. There are, in fact, three systems of low-pressure hot-water circulation—the two-pipe system, the one-pipe or ring-main system, and the overhead or drop system, and any one of these, or a combination of the three, can be applied.

In addition, there are the high-pressure and the thermal-storage systems. The two-pipe system is the oldest, and derives its name from the fact that the radiators are actually connected to the flow and return of the main circulation. The one-pipe system is a ring circuit, from which branches are made to the various radiators. The most suitable, however, in modern buildings is the overhead or drop system. In this the main flow is carried direct to the highest point, so that circulation is stimulated to the greatest possible extent, while the radiators are connected to drop returns. Main horizontal pipes, with the exception of those at the top and bottom, which could be in the roof and under the floor respectively, are avoided. A further advantage is that the boiler can be fitted on a level with the lowest radiators.

The high-pressure system is a sealed continuous pipe coil working at a pressure of approximately 70 lb. per square inch. The thermal storage system is used primarily in conjunction with electric heating, since it allows the current to be taken at off-peak periods, when favourable terms can be obtained. The method is simply to store the energy in the form of heat in large water containers, the store of hot water being used gradually throughout the day. The disadvantages of this arrangement lie in high installation cost and in the fact that considerable space is occupied by the storage tanks. The same principle is applicable to the other fuels, for instance, with coke boilers, additional water can be heated during the day and stored for use at night, the maintenance charges being thereby reduced.

In the case of hot-water circulation systems heat is liberated either by the usual sectional radiators or by radiant panels. These may consist of separate cast-iron units with a flat surface, such as " Rayrads," fitted either on the face of or embedded in the walls or ceiling. An alternative type is composed of jointless pipe coils embedded in the floor, walls or ceiling, plastered over on the front so that in practice the heat is obtained from the surface of the structure. With the large heated surfaces obtained in this way it is possible to get adequate heating with comparatively low water temperatures.

Some of the advantages claimed for panel heating are :—It overcomes unsightliness and obstruction caused by exposed pipes and radiators ; can be applied to any scheme of decorations ; gives warmth to the occupants in less time when starting from cold ; wall streaking is considerably reduced, and, further, there are no lodgments for dirt, dust, etc., with resulting economies in decoration. Steam has in the past been fairly extensively used for central-heating purposes, but is now in disfavour, and the lower temperatures associated with water circulation are preferred.

Air as a heating medium has the disadvantage of very low specific heat per unit volume, and its use for heating purposes requires the construction of ducting occupying a much greater cross-sectional area than the corresponding water pipes. On the other hand, it combines the effects of heating and ventilation, and therefore serves a dual purpose.

Panel heating may be employed using local units heated either by gas or electricity, the supply of which may be centrally controlled. Gas-heated panels have been found very effective, and there would seem to be great possibilities for their extended use.

Choice of Systems for Various Buildings.

The design of the building usually determines the most suitable form of heating. For public halls, theatres and cinemas some types of factory air-conditioning plants are particularly suitable, as they not only provide the necessary heating, but also ensure the required amount of air change per person in relation to the seating capacity or the factory requirements. For local heating in corridors or small rooms, radiators or panels may be preferred. For offices and schools radiator or panel system would generally be more suitable, giving the necessary combination of radiant and convected heat to suit the circumstances. For greenhouses and similar buildings lineal piping is still the most effective, having a longer time lag and less temperature fluctuation. Whatever system is adopted, however, it must be capable of maintaining adequate temperature over long periods in spite of the sudden climatic changes common in this country.

It is normally necessary to maintain a constant temperature at a given point irrespective of outside temperatures and of the number of occupants of the room. This condition can be obtained by one of the thermostatic devices, which can be applied in various ways :—

(*a*) By a room thermostat in a central or key position directly controlling the fuel supply, maintaining a constant temperature at that particular position and a corresponding temperature throughout the building.

(*b*) By thermostats on various sections of the installation operating magnetic or motor-driven valves to regulate the flow of heating medium, and consequently the supply of heat, to that particular section. By this method it is possible to maintain different temperatures in different parts of the building.

(*c*) By thermostats attached to the radiators, which regulate the flow through them so as to maintain a constant temperature in the apartments.

A further refinement, known as the variostat, is a device which causes heat requirements to be anticipated according to the variations in outside temperatures, and this enables a more constant temperature to be maintained inside.

Thermostatic control cannot be too strongly recommended ; it is an essential refinement for almost any installation, and not only improves the comfort conditions, but also makes possible the strictest economy. The actual saving, of course, varies according to the installation and the fuel used ; in many cases it is quite appreciable, and may be between 15 and 30 per cent., which well justifies the extra cost of the equipment.

Hot-Water Supply.

The theoretical problems associated in the past with hot-water supply have all been successfully overcome, and there are now very many installations in which this medium is supplied from a central source. When carried out on a large scale, it becomes essential to employ a secondary circulation, operated by gravity or pump, to carry the water round the building. This secondary circulation, however, together with the storage tanks, pipes and boilers, unless suitably lagged, transmits a considerable quantity of heat. In order to reduce some of the losses it is customary to close the circuit at night. Further economy may be obtained at times, when the demand falls off, by reducing the storage in the cylinders, and this may be effected by means of a cut-out valve on the primary return.

The fuels now under consideration, gas and coke, fall into two well-defined categories, gas being a highly refined fuel, producing waste gases of an innocuous character, and capable of the highest degree of automatic regulation, while coke is a cruder and cheaper fuel.

The costs of these two fuels are shown in Table I (in comparison with those of electricity and oil). In this table the probable efficiency of application has been considered, and the final figures showing B.T.U. for 1d. represent the actual output of heat obtainable.

Table I.

Method of Heating.	*Fuel Cost*	*Fuel Cost per Therm*	*Overall Efficiency*	*B.T.U. per 1d.*
GAS.				
Medium Installation	6d. Therm	6.0d.	80%	13,333
Large Installation	4.7d.	4.7d.	80%	17,050
COKE.				
Medium-size Installation .. (C.V. 12,500)	31s. per ton	1.33	60%	45,200
FURNACE COKE.				
Large Installation (C.V. 13,000)	29s. per ton	1.24	60%	49,600
ELECTRICITY.				
Day Load	¾d. unit	21.9d.	100%	4,265
Off Peak Load	¼d. unit	7.3d.	90%	12,284
OIL.				
No. 2 Domestic (C.V. 19,000)	80s. 5d. per ton	2.227	60%	26,500
Crude (C.V. 19,000)	75s. 5d. per ton	2.13	60%	28,200
Creosote (C.V. 17,000) ..	65s. per ton	1.9	60%	29,400

Gas is an ideal fuel for central heating and hot water-supply. Its ease of control (whether by room thermostat, flow temperature or hand control), cleanliness, silence, quick pick-up, reliability, safety, absence of storage and very low maintenance cost, absence of smoke, soot or smell are some of the most outstanding advantages. Furthermore, a gas boiler occupies less space than any other type, and can be fitted at any level in an installation. The fuel supply is unlimited day and night ; the full heat output is available from the start at an absolutely constant figure, and the installation itself requires practically no attention in use. For hot-water supply, gas can be used irrespective of whether the load is continuous or intermittent, and there are already many installations for this purpose in hotels, flats, nursing homes, hostels, etc. Gas boilers can be fitted in the same installation with solid fuel boilers for use either in conjunction with them, or in their place, and calorifiers can be employed as usual, though with gas firing it is generally cheaper to heat water direct.

In any case a separate boiler can always be fitted to heat water direct for summer use or for periods when the heating boiler is out of action. Ventilation of the gas boilers is necessary, but the volume and temperature of the flue gases are both low and natural draught is generally used.

In connection with air heating, gas has the advantage that it can be directly applied, instead of using steam or hot water as an intermediate heating agent, and as a result gas-fired air heaters are considerably more compact than alternative systems using other fuels.

In view of the advantages mentioned above, it may reasonably be assumed that gas will eventually be used for the greater part of the central heating and central hot-water supply systems throughout the country where it is possible to reduce the price and to make it strictly competitive with other fuels. These facts have been realised by the Gas Light & Coke Company, and its charges for gas for central heating have been appreciably reduced, so that gas firing may often be considered worth while when all the facts of the case are considered.

As an example, the block rate charges for the Central area are quoted in the table below :—

Therms per quarter.	*Price per therm.*
1— 100	8.6d.
101— 1,000	6.8d.
1,001— 2,000	6.0d.
2,001— 3,000	5.75d.
3,001— 4,000	5.5d.
4,001— 5,000	5.25d.
5,001—20,000	5.0d.
20,001—50,000	4.75d.
All over 50,000	4.5d.

The new tariff which has now been adopted is termed the "Block Rate," and is equivalent in its lower ratings to electricity at 0.16d. per unit.

This block rate also applies to hot-water supply when used in conjunction with central heating.

Methods of Gas Firing for Central-Heating Purposes.

The use of gas in central heating and hot-water supply are apparently unlimited, and for the partial heating of flats, gas-fired central-heating systems are particularly suitable. They are equally applicable to the heating of lock-up shops and banks where automatic clock control can be applied so that the heating is turned on at any predetermined time. The same technique could be applied to blocks of offices, large stores and public buildings. For medium-sized private houses, where room control is fitted, say, in the hall, it is not necessary for the boiler to have any attention ; the control is simply turned down at night and up again in the morning to 60° or whatever temperature is required, or, alternatively, clock control can be fitted.

A comprehensive range of boilers of different designs is available for this work, and types ranging from 32,000 to 1,200,000 B.T.U. per hour can be obtained. The Potterton "Rex" and the National "Ideal" boiler are both cast-sectional boilers with bottom firing, and are somewhat similar in appearance, and alternatively steel tubular boilers of both vertical and horizontal types are made by Town Gas Boilers, Ltd., while a further type is the Auto Control Co.'s "Vesta" boiler, which is fired from the top and ventilated by a small electric fan. All these are highly efficient and fitted with all the necessary control refinements. Owing to the various conditions under which these boilers are used, it is difficult to give definite gas consumptions. However, as a general guide to the probable consumption over a whole season, for a day load with a building heated each day during the season, a figure of 20 to 25 cu. ft. of gas per hour per 100 sq. ft. of radiator surface may be taken.

Conversion of Solid Fuel or Oil-Fired Boilers.

The conversion of solid fuel boilers to gas firing has recently been the subject of investigation by our research department, and as a result it is now a practical proposition to convert coke or oil-fired boilers to gas firing, using a series of floats with flat-flame luminous burners, or else an aerated burner with a radiating refractory block. The gas can be controlled by remote thermostat and time switch in the usual way. This development, of course, is not altogether new, as conversions have been carried out by private engineering firms for some time, but it is now possible to effect the conversion with a greater degree of efficiency and simplicity.

The approximate cost of conversion for a boiler of, say, 500,000 B.T.U. per hour capacity is £30, and in operation an efficiency of not less than 70 per cent. is now obtainable, which compares satisfactorily with the figure of 80 per cent., which may be taken as the efficiency of a boiler originally constructed for gas. Such a conversion was recently carried out at the Gas Light & Coke Company's own premises with a Britannia boiler used for heating offices and stores, and comparative tests were carried out over a period of 22 weeks. Room control and time switches were both fitted, and the temperature was maintained at 61° to 63° F. The average cost of coke per week for the previous three years had been £3, and the average gas consumption during the test was 242.5 therms per week, equivalent to a weekly cost of £6 7s. For the season, the total cost of coke was £66, plus labour £16 10s., total £82 10s.; and the total cost of gas under the new block rate charge was £139 14s. It will be realised that had a gas boiler been used in place of a converted coke boiler the comparison would have been more favourable to gas, and except where it is essential to reduce the initial cost of a converted installation to a minimum it is recommended that a properly constructed gas-fired boiler should be installed at the outset.

Actual Installations.

Gas for central heating is becoming increasingly popular, both in London (where the Gas Light & Coke Company alone has more than 200 installations), and in the Provinces.

One notable installation of this form of heating is to be found at the Greyhound Racing Track and Sports Stadium at the White City, Shepherd's Bush. The building consists of three large dining terraces with glass fronts and sides 100 ft. in length and 12ft. high. There are, in addition, an elaborate ballroom and various rooms for the betting transactions. These rooms are situated both in the main building and around the track. There are also large dressing-rooms for the athletes taking part in the various sporting events.

For the heating of the dining terraces, electric tubular heaters, supplemented by oil heaters, were originally used, but the objection to the oil heaters was the formation of a film of oil on the glass, which not only prevented a clear view of the racing at night time, but also gave the window cleaners considerable trouble to remove it. Both electric and oil heaters have been completely displaced by the gas installation.

Owing to the exposed lofty position and very large area of glass, it was found necessary to provide radiators giving out a high percentage of radiant heat, which could be directed on to the diners, instead of depending on the whole of the air being heated to the required degree.

Radiators were fitted throughout, heated by three R type Victor boilers, providing an installation of approximately 3,600 sq. ft. of radiating surface. The installation is operated by gravity without acceleration, and the temperature of each of the glass terraces and of the ballroom is controlled by thermostats of the magnetic valve type. If necessary, each apartment could be maintained at a different temperature, the thermostat at the boiler controlling the gas supply.

The smaller installations—six in all—are heated by separate boilers and coils, each housed in a small hutch let into the wall, fitted with steel doors and ventilated by air-brick. This is a point of interest, as it shows a means of fitting a boiler without a flue, and, further, avoiding any condense troubles. The hutches are built of breeze slabs, and are just large enough to accommodate the boilers only. Consequently the slabs are heated to practically the same temperature as the boilers, and condensation is prevented.

There are bathing and dressing-rooms for the use of the footballers. Separate accommodation is provided for the home and visiting teams, each having a plunge bath of 400 gallons capacity. There are also seventeen shower baths, 24 basins, various slipper baths, and a drying-room is provided for the players' clothes.

To provide hot water for the two plunge baths a 450 gallon storage tank was installed, the water being heated by a battery of gas heaters. The heated water, when required, is discharged rapidly through 1½ in. draw-offs into the baths, thereby avoiding heat losses which would occur if the water were allowed to run slowly.

All the dressing-rooms, bathrooms and corridors are heated by pipe coils provided under the seats in the dressing-rooms, radiators being adopted in the other rooms—the total heating surface amounting to 650 sq. ft.

The whole of the water heaters, as well as the larger boiler for heating the players' building, are housed in a boiler-room below ground level. The chimney flue is lined throughout. A draining pit and discharge pipe are provided at the bottom of the flue.

Gas-fired air heaters without hot-water circulation are now being installed with satisfactory results for Turkish baths, film-drying rooms, churches, etc., the air being filtered and passed through the heater by an electric fan. Alternatively, hot air may be introduced into a room simply by natural draught.

Coke.

Coke has provided excellent service for central heating and hot-water supply for many years, and extensive research has recently been carried out with a view to improving the quality, grading and delivery of this fuel.

Improvements have now been brought into existence whereby coke boilers can employ the refinements associated with gas. It has been found possible to apply room control and automatic feed, and as a result considerable economy in both fuel and labour has been obtained. Thermostatic control can be applied, either by operating motor-driven valves and so controlling the circulation on any particular circuit, or by using a central position as a key-room to control the whole of the building. The equipment consists of one of the usual room-type thermostats, wired to a small geared motor which operates the main damper, air shutter, and check damper on the flue, so regulating the draught to the boiler and maintaining the required output of heat. This system is equally applicable to boilers supplying hot water and to those supplying steam, regulated by a pressurestat. The cost of this thermostatic equipment, fitted complete, will depend on the length of wiring from the room control to the boiler. £25 however, should cover the outlay for a medium-sized installation. Except with the smallest boilers, the saving of fuel alone would justify the expense, and there is the additional advantage of a practically constant temperature being maintained.

For small and medium-sized systems the cast-iron sectional boiler is still pre-eminent for use with coke, but in tall buildings, where the static pressure is high, steel boilers are preferable. Recent developments in boiler construction, however, have made it possible to charge a fresh type of central-heating boiler which will burn without refuelling around the 24 hours. This does not mean that the fire is blanketed by the usual heavy firing, but that the boiler has a magazine at the top, in which the fuel is stored, and from which it gradually trickles down on to the sloping grate bottom as the fire demands ; in this manner a continuous gravity feed of fuel is obtained. By drawing a shoe or shutter from the bottom of a hopper, the fuel is fed direct into the boiler without handling, so that except for forcing the boiler, which requires occasional rocking of the grate bars, the only labour needed is for de-ashing each morning. A plant working on these lines has been in operation for over twelve months with very satisfactory results, and other plants are now being installed in two very important buildings.

NAVAL HYGIENE

By Surgeon-Commander H. St. C. COLSON, M.B., B.S., D.P.H.

EXTRACT FROM PAPER READ BEFORE THE ROYAL SANITARY INSTITUTE

PORTSMOUTH, MAY 11th, 1934

NAVAL hygiene follows the principles of hygiene in general, but owing to the complicated structure of modern warships, variations in the application of these principles have to be adopted.

The chief problem of naval hygiene is ventilation ; ever since ships have been decked in, this has been a difficult problem. Numerous factors make the ventilation of ships difficult. The modern warship has steel sides through which no diffusion can take place. It is divided by watertight bulkheads into numerous comparatively small compartments, each of which has to be separately ventilated. The sides of the ship may have small openings—ports or scuttles—but in many ships these, on account of armour, may be absent, and the mess decks, workshops and other living spaces have often no natural light and no natural ventilation other than an occasional draught that may come down a hatchway under favourable conditions.

The ship may have to serve in hot or cold climates.

Heat from internal sources such as steam pipes, bakeries, galleys, bathrooms and food ovens—so-called "wild" heat—has to be overcome.

It must be remembered that the officers and men in modern warships, unlike their predecessors in the days of sailing ships, spend little of their time in the open air on the upper deck. The greater part of the ship's company work below in such places as engine rooms, workshops, offices and other places between decks which often have no natural light and no natural ventilation. Even those whose duty is on the upper deck, sleep, feed and spend most of their off-duty time between decks.

It is impossible to compare shore standards of cubic and superficial space with those in a ship of war. Minimum requirements are laid down by the Board of Trade for the mercantile marine ; but in the Navy afloat there is no definite floor space per man laid down, and it varies largely in different classes and types of ship. As far as possible 200 cu. ft. per man is allowed.

The limited space of the mess decks only permits of 18 in. between hammocks, which just gives a man sufficient room to turn in his hammock without touching his neighbour. Overcrowding is unavoidable owing to the limited space and the large number of men that the modern warship has to carry. These limitations of cubic space have to be overcome by increasing the rate of change of air. This is brought about by a plenum system of ventilation, with the use of high-speed electric fans. Fresh air is drawn down from the upper deck through water-excluding ventilators and distributed through ventilating trunks into the living spaces. Steam heaters are fitted in the ventilating trunks so that the incoming air can be warmed if necessary. These fans can supply up to 4,000 cu. ft. of fresh air a minute. The objection to forcing large quantities of air into living spaces is draught, especially in cold weather ; sailors, being human, object to draughts, no matter how good they are told that fresh air is for them. To lessen these draughts the incoming air is discharged through punkah louvres ; these consist of a movable ball-and-socket arrangement through which the air passes, so that the current of air can be pointed in any direction. Certain compartments in a ship, such as pantries, bathrooms, store rooms, paint rooms, etc., which may contain obnoxious smells, excess of moisture or harmful gases, are ventilated by an exhaust system with natural intakes.

The maintenance of air temperature in the living spaces of warships is another difficult problem. Any ship may have to serve on a station such as the America and West Indies station, where the temperature may vary between 100° F. in the shade and zero. As a ship is built of metal, the inside of a ship rapidly tends to assume the temperature of the air and water outside. To lessen this an inner lining is placed in the ship forming an air space. The " wild " heat, referred to before, raises the temperature within a ship, an advantage in cold climates, but a curse in the tropics. It is counteracted by lagging bulkheads and steam pipes. Generally speaking, in cold climates ships are warned by passing the incoming air over steam pipes and by the use of stoves and electric radiators. In hot climates, ships are painted white, awnings are spread, windsails and windscoops are used, extra table fans are issued, and men wear appropriate clothing and are encouraged to sleep on the upper deck.

Humidity is another important factor closely associated with health, and comfort, especially in very cold or very hot climates. In cold weather when the air within a ship is warmer than that outside, moisture is liable to condense on the ship's side. A ship's company of 1,000 men contributes about 280 gallons of moisture a day from their skins and lungs. Other sources of humidity are deck scrubbing and the accidental entry of sea water. " A dry ship is a healthy ship " is an old but still true saying, and every precaution is taken to keep living spaces free from dampness by limiting the amount of water used between decks and by free ventilation.

BUILDING RESEARCH STATION, GARSTON, NR. WATFORD, HERTS.

RAYS ON THE SKIN

By A. F. DUFTON, M.A., D.I.C.

THE controversy about " nose-opening " rays has once more been raised in the public Press and the position has been reviewed by the Medical Correspondent of *The Observer*. "Some years ago," he writes in the issue of September 23rd, " Sir Leonard Hill stated that he found the rays from an electric fire caused congestion of the nose and a feeling of stuffiness, and that rays from an incandescent lamp counteracted this effect. In the report of the Building Research Board for 1933, issued last week, an account is given of an investigation carried out to test the truth of this statement. Experiments were made with eighty-five subjects, and no difference was found in the degree of effort needed to inspire air as a result of changing the type of radiant heat employed. It is said that any rapid warming of the skin will cause a certain amount of congestion of the nose and, as for the protective effect of an incandescent source of heat, it was found that the sun is actually a powerful ' nose-closer.'

" To these criticisms Sir Leonard Hill has since replied, and there does appear to be some possible source of error on one or other side, since results obtained by trained investigators gave such contradictory results. Sir Leonard Hill says that his own tests were more delicate, in that he reduced considerably the normal airway in the nose before turning on the source of heat. He also found that the sun eased the breathing, except when screened by window glass. The breathing is also easier when the sun's rays are screened through special glass which only allows the passage of the ultra-violet and short infra-red rays. It may be that the matter is largely a question of individual sensitivity, but to refute this Sir Leonard Hill quotes an experiment on a group of sailors on H.M.S. Excellent where 85 per cent. of fifty-four subjects found their breathing more difficult when exposed to radiant heat from an electric radiator, and this was eased in 43 per cent. by switching on two electric lights. There the matter must rest for the moment, but it is obviously of great importance that the controversy should be settled."

It will be clear from this statement that the paper on "The Influence of Heat and Light upon Nasal Obstruction,"[1] by Winslow, Greenburg and Herrington, which has recently appeared in the *American Journal of Hygiene*, is particularly opportune. Professor Winslow, M.D., is the Director of the John B. Pierce Laboratory of Hygiene at Yale University and for many years was chairman of the New York Commission on Ventilation. The conclusions given at the end of the paper are worthy of attention and are reproduced below without comment.

> "1. It has long been recognised that the walls of the nasal passages exhibit certain reactions to thermal conditions of the environment which manifest themselves in a varying diameter of the airways. We find that these changes can be measured with reasonably satisfactory results by connecting one nostril with a recording tambour and observing the pressure variations recorded as a result of ordinary respiration. This procedure, however, is only suitable for the detection of rather considerable alterations ; and if marked variations in general atmosphere temperature occur, changes in the diameter of the airways may be masked by alterations in depth and rate of respiration. The spirometer method, described in the present paper, depends on the measurement of the time taken by a measured quantity of air under a fixed pressure to pass in at one nostril and out at the other while the subject holds his breath. This method is obviously independent of respiratory activity and has proved both more delicate and more reliable than the tambour method.
>
> "2. We find that constriction of the nasal airways ('nose-closing') can be produced with reasonable certainty and constancy by
> *a* Exposure of the skin to the rays of a dark-glow radiant heater,
> *b* Immersion of the arm in hot water,
> *c* Exposure to a high atmospheric temperature.

---

[1] *Amer. Journal of Hygiene*, 1934, vol. 20, pp. 195-217.

" These reactions appear to be direct responses to the warming of the skin and there seems to need to postulate qualitative effects related to specific electro-magnetic wave-lengths. Reactions are marked only in susceptible subjects characterised by deviated septa or other nasal abnormalities ; but they can apparently be demonstrated in lesser degree in normal subjects by the more delicate spirometer method.

" 3. We find no very definite evidence of what could properly be called a ' nose-opening ' effect produced by either cold water or cold air. When the skin is chilled, the airways may return to normal or (in a cold atmosphere) may even show a moderate amount of obstruction which we interpret as perhaps due to excessive secretion provoked in certain subjects.

" 4. The addition of the influence of light rays of shorter wave-length to the longer rays of the dark-glow heater by directing an electric light bulb on the face (in addition to the heater) was associated in the great majority of our experiments with a further increase in congestion. There seems, from our data, no reason to assume any real antagonistic influence or any specific effect upon nasal congestion of rays of definite wave-lengths.

" (As this report was being prepared for the Press, a communication by A. F. Dufton and T. Bedford, entitled ' Nose-opening Rays ' appeared in the *Journal of Hygiene* (Vol. 33, p. 476). The methods of study and the conditions observed are somewhat different from those presented here ; but the general conclusions —that ' nose-closing ' is a real phenomenon due to heat rather than to specific electro-magnetic wave-lengths, and that ' nose-opening ' can not be demonstrated under the conditions described by Hill—are the same at which we have arrived.) "

It should perhaps be pointed out that in the experiments on the sailors of H.M.S. Excellent, quoted by Sir Leonard Hill, the phenomena are explainable on the hypothesis that the light antagonism was dependent upon a subjective psychological reaction ; it is not necessary to postulate any direct response of the skin to specific wave-lengths.

In conclusion it may be mentioned that the subject of nasal obstruction by infra-red rays is now being studied by the rhinological clinic at the University of Groningen. The results of this investigation will be awaited with interest.

NATIONAL PHYSICAL LABORATORY

THE Executive Committee of the National Physical Laboratory in their Report for the year 1933* refer to the condition of industry which has been reflected in the activities of the Laboratory by the continued small demand for industrial investigations and routine tests of instruments. While it has not been possible to expand the facilities available at the Laboratory so much as the Committee would have wished, every effort has been made to press forward with the research programme of the Boards and Committees of the Department of Scientific and Industrial Research and certain progress has been made as evidenced in the Report.

Heat Transmission between Metal Pipes and Air Stream.

The work for the Engineering Committee of the Food Investigation Board has been continued. The first stages of the investigation designed to ascertain the basic principle of air-cooling " batteries " of pipes have revealed the high importance of turbulent motion and the twofold superiority of a transverse air current over one parallel to the pipes. The numerical relations found for hot pipes are followed also by cold pipes, even when snow-coated, provided the variables concerned are measured at the outer surface of the pipe or deposit.

The problem is essentially one of the transference of heat between two fluids through the medium of a " battery " of pipes, the fluids in refrigeration work being cold brine circulating within the pipes and a stream of air enveloping the pipes. The present investigation has been concerned principally with the practical case of iron pipes of diameter 1⅞ in., arranged in batteries of either the " square " or the " staggered " formation, at a spacing of 4½ in. The pipes were supported transversely in a closed-circuit horizontal wind tunnel, and measurements have been made only on the transfer at the outer surface of the pipe, since the laws at the inner surface are sufficiently well known. For convenience, the initial measurements were made on pipes hotter than air, and in such cases the pipes were heated more conveniently by an internal electrical heater than by passing hot fluid through them.

The main results of the work with hot pipes show that for any given transverse layer in the battery of pipes, and for a fixed degree of turbulence in the approaching air stream, the observations can be correlated by the principle of dimensions, by plotting Vd/ν against $H/k\theta$, where H is the heat loss per second per unit length of pipe, V the air speed, d the pipe diameter, θ the temperature excess of the pipe over the air, and υ and k are respectively the kinematic viscosity and thermal conductivity of the air, taken at a temperature mid-way between that of the air and that of the pipe surface. When plotted in this way, points with widely differing temperature excesses all fall on a single curve.

---

* The National Physical Laboratory Report for the Year 1933, 264 pp. 50 illus. Published by H.M. Stationery Office, London, 1934. Price 13s. net.

The effect of eddy motion in increasing the heat transmission was found to be nearly 100 per cent. when the air stream approaching the battery was first made highly turbulent by inserting a frame of wooden laths in its path.

When the pipes are colder than the air, the same numerical laws are found to hold as when they are hotter. This is equally the case when the pipes are covered with snow deposit, provided that d in the formula above refers to the outside diameter of the deposit and that θ refers to the temperature difference between the air and the outer surface of the deposit. Although the law is the same, the heat transfer between the pipe and the air for a given temperature difference between the two is, however, reduced, for the reason that υ and k are considerably diminished at low temperatures.

In addition to batteries of pipes set transversely to the air stream, longitudinal pipes have been studied. The laws for these differ in many respects from those for transverse pipes. Thus the heat transmission decreases down-stream, instead of increasing, and the relationship between the two variables mentioned previously is linear in the case of longitudinal pipes. The effect of eddy motion is, as before, to increase the heat transfer, particularly in the sections first met by the air. It may be of interest to note that, other things being equal, the heat transfer from a longitudinal pipe is of the order of one half that from a transverse pipe.

It is proposed to carry out a similar investigation on pipes provided with fins or gills, which are intended to facilitate the heat exchange with the air.

Wet- and Dry-bulb Psychrometer.

For the measurement of vapour pressure a " wet- and dry-bulb " psychrometer has been constructed, consisting of two thermojunctions composed of fine nichrome and constantan wires, a wrapping of fine cotton serving to retain the moisture on the wet junction. It has been found that the depression of the wet thermojunction becomes less sensitive to ventilation the smaller the diameter of the wire. Hence, by the use of a thermojunction of very fine wire, it is possible to work with extremely low air velocities and yet obtain true wet-bulb depression. If the instrument is used in " still " air the values obtained for the relative humidity are only 2 or 3 per cent. higher than the true values. The distribution of wind velocity above the plane surface has been mapped by means of an anemometer based on the deflection of a short length of quartz fibre, mounted parallel to the surface and normal to the directi of the wind. Measurements have also been made to determine effect of a ridge projecting a few millimetres above the front e of the plate. It is found that such an obstacle shields the are surface in its immediate neighbourhood, and thereby reduces rate of evaporation from this region. It, however, introdu greater turbulence into the air flowing over the remainder of surface and this increases the rate of evaporation. The net e for a 4 mm. ridge and the size of plate mentioned is an increa about 15 per cent. in the rate of evaporation. The rate of transfer from the dry plate is similarly affected.

Thermal Properties of Foodstuffs.

Some of the recent developments in refrigeration have cen around processes for the rapid freezing of meat. In these the m cut up into fillets, is cooled to much lower temperatures than is case with the customary method of freezing carcases in their enti A knowledge of the thermal properties of meat at low temperat has thus become a matter of practical importance. Measurem have accordingly been made of the thermal conductivity, specific heat and the thermal diffusivity of samples of fresh Sc beef.

The thermal conductivity was measured by a plate method plates measuring 4 in. square, the whole apparatus being se and totally immersed in a bath of acetone cooled with solid ca dioxide. The value found for the thermal conductivity in the range – 40° C. to – 80° C. was 0.0038 c.g.s. unit.

The specific heat was measured over two ranges of temperature. For the range between – 80° C. and – 180° C. the procedure adopted was to transfer a sample cooled to – 80° C., into a bath of liquid oxygen, and to observe the weight of the latter boiled off in the process of cooling the meat. Similar tests were made on samples of partially dried meat of known moisture contents. The specific heat of fresh meat between – 80° C. and – 180° C. was found to be about 0.25 gramme calorie per 1° C. per gramme, whilst that of completely dessicated meat was about 0.20. The specific heats of the same materials measured at temperatures slightly above that of the room were 0.85 for fresh meat and 0.35 for dried meat.

From the thermal conductivity, specific heat and density, the coefficients of thermal diffusivity of fresh meat was calculated and found to be 0.009 c.g.s. units.

Thermal Conductivity of Building Materials.

Of the various wall sections and plaster materials tested for the Building Research Board, mention may be made of two wall panels, each consisting of four superimposed layers of corrugated brown paper, the corrugations in adjacent layers running perpendicular to each other, and the layers being interleaved with sheets of brown paper. In one of the panels the paper partitions were covered with aluminium foil, and in the other were left in their natural state. The coefficient of heat transmission for the panel coated with metal was found to be approximately 5 per cent. less than for the one with plain paper, and for the latter the equivalent thermal conductivity at 30° C. was only about 25 per cent. greater than for slab cork.

Noise Transmission and Suppression.

An inquiry is in progress on behalf of the Steel Structures Research Committee, to ascertain how steel-framed buildings compare with other types of building as regards the transmission of noise. Various aspects are being considered, notably the transmission through walls and floors of air-borne sounds and mechanically delivered impacts, and the transmission in the structure of noises due to sanitary fittings, or to machinery such as lifts, water circulators and ventilating fans. Difficulty arises from the fact that it is not easy to find buildings which provide strictly comparable conditions, but a number of buildings have been studied and the problem is being clarified. It is satisfactory to know that the work is being continued.

Belts for Power Transmission.

The relative movement, or "creep," which takes place between a cast-iron pulley and a leather driving belt has been explored over the arc of contact by means of a specially designed stroboscopic device. The observed values of creep were found not to be in agreement with the values calculated in the usual way, on the assumption of a constant coefficient of friction, using the measured elastic modulus of the belt. Careful measurements were then made of the coefficient of friction at various rates of slip, covering a range corresponding to the observed creep in the running tests. It was found that the friction could be expressed by the empirical formula :

$$\mu = \frac{Ar}{B + r} + C,$$

where μ is the coefficient of friction, r is the rate of slip (or creep), and A, B and C are constants for any one belt or pulley surface.

Using this formula and integrating the creep over the arc of contact there was still no satisfactory agreement between the observed and calculated amount of creep, and it was therefore concluded that the elastic modulus must be a variable depending on the rate of change of load. Experiments were then made on the rate of oscillation of a weight suspended from a length of leather belt. From these tests it was found that there is a considerable increase in the apparent value of the elastic modulus as the rate of loading is increased. Apparatus has now been constructed for measuring the modulus of the belt when it is running on pulleys, and it is expected that this will enable the exact relation between modulus and rate of loading to be determined.

Heat Loss from a Bare Pipe.

A knowledge of the heat loss from a bare pipe is required in order to calculate the saving effected by heat-insulating materials. At present the values of the heat loss have been determined experimentally up to a temperature of 600° F., but the laboratory is frequently asked to undertake tests on insulating materials at a pipe temperature of 1,100° F. A special apparatus is therefore under construction for the purpose of determining the heat loss up to 1,100° F. Preliminary experiments have shown that it is possible to load nickel-chrome alloy wires to such an extent that the heat required can be provided by a single layer of wires close to the inner surface of a 4 in. diameter pipe. With a heater of this form the major part of the radiation is radial, and loss of heat by axial radiation towards the ends of the pipe can be reduced to a negligible amount.

NEW BOOKS: WARMING BY ELECTRICITY

Electric supply authorities in their desire to increase the use of their energy are gradually reducing its price, with the result that heating by means of electricity is becoming a more economical proposition. With the increasing adoption of electric heating it is surprising that up to the present no book on the subject has been published in this country and consequently, no excuse is necessary for the appearance of Mr. F. C. Smith's book.* Although the author hopes that the work will be of use to architects, engineers and others, it is evident that his original idea was to educate members of the electrical profession in the principles of the art of warming buildings. As he states in the preface that to handle electric warming problems successfully demands a knowledge of two branches of engineering—heating and electrical; the former dealing with the flow of heat and the latter the flow of electricity. He has assumed a knowledge of the latter and has only dealt with it briefly. In spite of this, however, the book will appeal to heating engineers as well as electrical engineers and those engaged or interested in the application of heating. Chapter 1 is devoted to the general principles of heat, electrical fundamentals, systems of supply and the purchase of electrical energy. Some of the figures in this chapter require checking as we find in Fig. 1 the absolute zero is given as −480° F.; the conversion constants for calorie and B.T.U. should be 3.968 and 0.252; the latent heat of fusion of ice is more generally given as 144 B.T.U. and the names of Lambert and Kirchhoff are incorrectly spelt. Chapter 2 is interesting and deals with the warming effect of electric heaters, warming rooms by convection, radiation, electric fires, hot water radiators, tubular and panel heaters. Chapter 3 discusses the heat required by rooms and points out the need for more exact calculations for electricity; convection and radiation heating are described and how to estimate the load for various buildings are dealt with. Chapter 4 carefully considers the subject of intermittent warming and the important question of the warming-up period. Those requiring information on thermal storage will find in Chapter 5 a lucid treatment of the subject and details on the principles of electrode boilers. Economy in cost of operating a heating system has to be thought of and Chapter 6 deals with the consumption of energy by the electric warming plant and the author points out that thermostatic control does not mean a constant internal temperature as the make and break may cause the temperature to oscillate 5 to 7°. The degree hour method is also described. The last chapter deals with the difficult subject of temperature guarantees and also relative fuel values. Altogether the book can be recommended to those seeking information on the subject. The book is well produced, but more care should have been taken in reading the final proofs, as in the preface we find the " Institute " instead of Institution, and the names Reyrolle and Brackett are given wrongly.

---

* "Warming Buildings by Electricity," Frank C. Smith, A.M.I.H.V.E., A.I.E.E. 5½ x 8¾ in. 168 pp. 54 illus. Cloth. Published by E. & F. N. Spon, Ltd., London, 1934. Price 8s. 6d. net.

HEATING AND HOT-WATER SUPPLY

EVERY teacher knows the difficulty encountered in trying to explain the elementary principles of a subject clearly and understandably to those of his students who are taking their first lessons. This is particularly so when the subject is one which might easily develop into a discourse above the heads of the students. Mr. J. W. Cowan is to be congratulated on overcoming this difficulty in producing his small hand-book,* which provides brief explanations of the natural laws upon which the success of hot-water heating and hot-water supply installations depends, in such an interesting manner that it should, as he desires, enable the reader to grasp the fundamental principles involved. Chapter 1, on expansion and circulation of heated water, gives an excellent example of a weighted rope on pulleys to explain how the " rising " of hot water or warmed air is due to the downward movement on the part of another colder and therefore heavier column of water or air. Units of heat measurement, water column and pressure and the meaning of the term " circulating head " are dealt with in the next chapters. Chapter 5, on elementary calculations of capacity of tanks and pipes is simply explained, and we agree with the author that it is difficult to imagine why cylinders should be listed with two capacities, " nominal " and " actual," and we hope the British Standards Institution will deal with this question. Chapter 6 discusses modes of heat transmission, conduction, convection and radiation. The capacities of heating installations in Chapter 7 deal with heat losses, radiator transmission and pipe sizing. The author should have explained that radiators have varying heat emission coefficients, and are not all rated at 1.5 B.T.U. per sq. ft. per degree difference of temperature. Whilst this chapter explains pipe sizing clearly it is felt that the omission of a chart or tables will make it difficult for a beginner to grasp. Chapters 8 and 9 deal with hot-water supply, expansion and storage tanks and hot-water cylinders, each being carefully considered, though the author is over generous in calculating the storage and boiler size, as it is not likely the bath, lavatory basins and sink would be all in use at once, and most likely the boiler will have more than one hour to provide the maximum demand. The fallacy of the dipped feed pipe is discussed. The last chapter considers air locks, their cause and remedy. The book will be appreciated by anyone who wishes to take the first step on the subject and fulfils the author's aim to provide a preparation to a study of a more comprehensive treatment. The book is well printed, and only two printer's errors were noticed, the word " reserve " on page 85 being misspelt and " tank " instead of " tanks " on page 97.

---

* " Central Heating and Hot-Water Supply." J. W. Cowan, A.M.I.H.V.E, 5 in. x 7½ in. 138 pages, 24 illus. Cloth. Published by Percival Marshall & Co. Ltd., London, 1934. Price 3s. 6d. net.

ABSTRACTS

Theatre Ventilation Problems. 697, 725.825

Development of the motion picture as a form of entertainment has involved numerous problems in connection with the design of film theatres in the United Kingdom, not the least of which is that of efficient ventilation. The London County Council stipulates that 1,000 cu. ft. per hour of clean air must be provided per person. This figure is arbitrary and whether it affords adequate ventilation must depend upon the design of the theatre itself.

In many theatres abroad, the system of ventilation adopted is to draw the air in near the roof (the air being heated in winter and cooled in summer). Such a system is recommended in certain instances, but where nearly everyone in the audience smokes, as is the case in the United Kingdom, this system is thought inadvisable. Another point which has been discovered is that in a hall where smoking is permitted, if fresh air is delivered near the top of the hall and extracted again immediately below, there is a tendency to produce smoke clouds which drift across the beam of light from the projector. This difficulty has been overcome in some of the largest and most modern British theatres by blowing in the greater volume of fresh air at a point mid-way between the stalls, floor and ceiling, upward through the risers of the balcony, and downward from the stalls ceiling, and extracting at both the top and bottom on each side of the building. This method has proved successful, the air and smoke clouds from the occupants of the balcony being drawn upward and away from the projector beam to the sides of the hall, while the air and smoke from the stalls is drawn downward and also to the sides of the buildings, the audience's line of vision and the projector beam being in no way obscured by smoke. At the same time an even temperature is maintained in both stalls and balcony, instead of the upper parts of the house being several degrees warmer than the floor level, as frequently happens. (*Heating and Ventilating*, U.S.A., August 1934.)

Smokeless Fuel. 621.182

The Fuel Research Board have carried out some valuable tests in order to determine the amount of heat required to ignite various kinds of solid fuel in open grates. The tests comprised the ignition of a fixed bulk of carefully sized fuel in a single charge by means of a gas lighter, the minimum quantity of gas required to enable the fuel to support independent combustion being observed. Experience has shown that, if a fuel requires more than 2,240 B.T.U. for ignition under the standardised conditions of test, then difficulty is experienced in igniting the fuel with a reasonable amount of wood and paper and, moreover, the fire must not be allowed to burn too low before fresh fuel is added.

The difficulty of ignition of gas coke, which usually requires about 4,500 B.T.U. is one of the reasons why this fuel is unsuitable for ordinary open grates and, although what is termed a gas poker, which consumes gas at the rate of about 22,400 B.T.U. per hour, may effect ignition, the fire must never be allowed to burn too low before being refuelled. This means constant attention in order that it may not fall below the critical condition. A good fuel, however, made by the process of low temperature carbonisation, is very easy to light, and in many cases 1,000 B.T.U., or even less, is all that is required for this purpose—in fact, it is often easier to light than coal. Perhaps even more important still, it has been shown that the solid fuels made by low temperature carbonisation, in addition to having this property of easy ignition, have a high radiation efficiency. Recent tests on the best of these fuels have shown a radiation efficiency of as much as 33 per cent. as compared with 22 per cent. for coal burnt in the same grate and under the same conditions. It is customary to allude to this as a gain of 11 per cent., this is incorrect, it is a gain of 50 per cent., being half as much again.

The calorific value of some of these so-called low temperature fuels (I say "so-called" because they give the highest temperatures) is as high as 14,300 B.T.U. per lb., as good as or better than first-class house coal. It follows, therefore, that the whole of the increased radiation efficiency is enjoyed by the consumer, the yield of heat radiated into the room being as follows :—

From 1 lb. of best house coal of calorific value 14,300 B.T.U. per lb.

Total efficiency 22 per cent. = 3,146 B.T.U.

From 1 lb. of best low temperature smokeless fuel 14,300 B.T.U. per lb.

Total efficiency 33 per cent. = 4,719 B.T.U.

a gain of 1,573 B.T.U. on each pound, or 50 per cent. above the coal figure.

This figure confirms exactly the statement made by thousands of consumers that one ton of low temperature radiant smokeless fuel is equivalent to 30 cwt. of ordinary coal. Another reason for this economy in use lies in the fact that bulk for bulk the fuel is only half the weight of coal. This is most fortunate as it allows the rate of consumption of the fuel, reckoned by weight, to be much reduced, thereby taking the greatest possible advantage of its higher radiation efficiency. (Col. W. A. Bristow, M.I.E.E., *National Smoke Abatement Society*, London, June 8th, 1934.)

Chimney Draught. 621.183.8

It may be proved that the draught, measured in inches of water, produced by a chimney H feet high, is

$$D = 7.63\,H\left(\frac{1}{t_1 + 460} - \frac{1}{t_2 + 460}\right)$$

where t_1 is the temperature of the outside air and t_2 the temperature of the chimney gases.

By transposition we obtain the formula,

$$H = \frac{D}{7.63\left(\frac{1}{t_1 + 460} - \frac{1}{t_2 + 460}\right)}$$

from which we can calculate the height of chimney required to produce a draught D in. of water.

It will be seen from the first formula that the draught would be affected by an alteration in the value of any one of the quantities H, t_1 or t_2.

A formula much used for determining the chimney throat area is the following :

$$A = \frac{1}{14} \cdot \frac{WG}{\sqrt{H}}$$

where A = area, in square feet,
W = lb. of coal burned per hour, per sq. ft. of firegrate,
G = total firegrate area in sq. ft.,
H = height of chimney, in ft., measured above the firegrate.

This formula is generally regarded as very reliable when applied to chimneys used in connection with a range of boilers. It requires slight modification when there is only a single boiler ; the constant $\frac{1}{14}$ being increased to, say, $\frac{1}{12}$ or $\frac{1}{10}$.

If there is any possibility of extensions to the plant at some future time, the area as found by the formula should be increased. (Edward Ingham, A.M.I.Mech.E., *The Steam Engineer*, August 1934.)

HEATING AND VENTILATING INDEX

Convectors. 536.2

Factors Affecting the Heat Output of Convectors. A. P. Kratz, M. K. Fahnestock and E. L. Broderick. 8 pp., 12 illus. Describing apparatus, test procedure and test data : *Heating, Piping and Air Conditioning*, July 1934.

Scale. 628.16, 621.194.4

Calcareous Scale, Its Origin and Formation. E. A. Smith. 3 pp., 6 illus. Dealing with sources of impurities in water which result in scale formation : *The Fuel Economist*, July 1934.

Oil Burners. 621.183.57

Tests Show Oil Burner Performance. E. M. Fernald. 4 pp., 5 illus. Describing tests with data obtained : *Domestic Engineering*, July 1934.

Insulation. 536.2

Testing Sheet Steel Insulation. J. T. Nichols. 3 pp., 3 illus. Describing method of tests and tests on sheet steel insulation : *Refrigerating Engineering*, August 1934.

Welding. 621.73

The Welding of Copper Pipes. W. L. Kilburn. 3¼ pp. Dealing with weldable grades of copper, filler rod, flux and welding technique : *The Parthenon*, August 1934.

Air Change. 697.91

Natural Ventilation and Air Interchange. A. T. Henly. 2½ pp., 2 illus. Dealing with calculation of air leakage due to the porosity of building materials : *Heating and Ventilating Engineer*, August 1934.

Fuels. 621.182

Automatic Heating Systems. George H. Hirons. 2 pp. Dealing with the theory of combustion : *Heating and Ventilating Engineer*, August 1934.

Ventilation. 697.92

Students' Text-book of Heating and Ventilation. Norman Wignall. 2 pp. Dealing with " pressure loss " method of designing and general principles of fans : *Heating and Ventilating Engineer*, August 1934.

Radiators. 536.3

Radiators and Convectors. A. P. Kratz. 3½ pp., 11 illus. Dealing with experimental work on radiators, convectors and enclosures : *Bulletin of Heating, Piping and Air Conditioning Contractors Nat. Assoc.*, August 1934.

Refrigeration. 621.575

Air Conditioning for Heating Contractors. L. L. Simmons. 4½ pp., 2 illus. Dealing with the theory of and equipment for steam-jet refrigeration : *Bulletin of Heating, Piping and Air Conditioning Contractors Nat. Assoc.*, August 1934.

Piping. 697

Copper and Brass for Heating Lines. Carter S. Cole. 3 pp., 5 illus. Dealing with use of copper and brass piping to meet corrosion problem, methods of fastening and determining proper size : *Heating and Ventilating*, August 1934.

Air Conditioning. 697.96

Air Conditioning in the Treatment of Pollen Asthma. Tell Nelson, B. Z. Rappaport, A. G. Canar and William H. Welker. 3¼ pp., 2 illus. Dealing with relatively low humidity, constant temperature and efficient filtering to prevent hay fever : *Heating, Piping and Air Conditioning*, August 1934.

Heating. 697

Influence of Stack Effect on the Heat Loss in Tall Buildings. Axel Marin. 5 pp., 9 illus. Describing investigations to determine the influence of heat loss from a tall building : *Heating, Piping and Air Conditioning*, August 1934.

Air Conditioning. 697.96

La Recherche du Confort Économique. R. Sabouraud. 5½ pp., 3 illus. Dealing with research on economic comfort by the study of equal comfort curves : *Chauffage and Ventilation*, August 1934.

Steam Heating. 697.52

Canalisations des Chauffages à Vapeur à Basse Pression. B. Guillot. 4 pp., 13 illus. Dealing with piping low-pressure steam heating systems : *La Couverture-Plomberie*, July 1934.

Chimneys. 621.183.8

Some Unsuspected Causes of Deficient Output in Steam Boiler Plant. Edward Ingham. 1½ pp. Dealing with chimneys, draught and formulæ : *The Steam Engineer*, August 1934.

INSTITUTION OF HEATING AND VENTILATING ENGINEERS

REPORT

AUTUMN SPECIAL MEETING, LONDON, OCTOBER 9th, 1934

THE Autumn Special Meeting of the Institution was held in the Lecture Theatre of the London School of Hygiene and Tropical Medicine, Gower Street, London, W.C.1, the President, Mr. R. Comyn Ching, in the Chair.

The following signed the attendance register :—Messrs. S. G. Saunders, E. R. Dolby, R. C. Ching, W. W. Nobbs, J. W. Cooling, Alcwyn A. Jones, Walter Scott, T. E. Chatterton, T. G. Noble, C. R. Allensby, A. Fleming Browne, F. S. Reed, J. C. Byles, A. B. Potterton, A. W. Beaven, T. E. Barnes, W. G. Case, Frank Selley, W. C. Clark, A. J. Ord, J. H. Francis, C. E. Ashton, T. H. Hatchett, H. N. Blake, A. E. Merrin, J. H. Bryant, W. E. Brown, A. T. Warren, A. T. Lambert, E. Brooks, N. E. Jackson, F. B. Turpin, J. W. Stitson, S. J. Warrell, H. A. Stirzaker, B. A. Pountney, L. A. Forni, A. J. Bundey, G. Nelson Haden, D. W. Torry, H. D. Mills, T. G. Connor, L. H. Baines, G. H. Rees, W. Stanley Crosier, G. W. Fowle, Harry Merrin, Ernest Berry, S. Adams, J. W. S. Cove, C. S. K. Benham, F. M. H. Taylor, J. N. Bottrill, C. W. Tidy, J. R. Kell, C. Ovenden, H. Leslie Egerton, T. G. Brooks, W. A. Smith, and H. B. Watt (Secretary) (London) ; W. E. Fretwell (Leatherhead) ; A. R. Johnson (Welwyn) ; B. R. Wingfield (West Drayton) ; Wm. H. Turvill (Tunbridge Wells) ; A. S. Naylor, Sam Fox (Halifax) ; Oswald Stott, James Elliott (Manchester) ; also the following visitors : Messrs. D. Legg, J. W. Harvey, W. D. Andrews, T. McDowell, R. G. Mennion, L. H. Shelley, F. T. Reid, W. Boon, William Lee, Jas. Worlin, F. G. Trasies, H. A. Smith, W. Aybrook, H. G. G. Thompson, J. Miles, H. J. Sharp, F. J. Eaton, J. A. Murfitt, E. J. Barlow, H. Gaund, F. N. Tunell, J. C. Hosken (London) ; A. F. Dufton (Garston) ; W. L. Howe (Nottingham) ; J. H. Collard (Liverpool) ; L. Walkden (Croydon) ; R. G. Grover (Uxbridge) ; A. B. Hill (Paris), and others were also present.

MINUTES.

The Minutes of the previous Meeting, held at Hastings on June 19th, 1934, which had been published in the *Journal*, were taken as read and signed as correct.

ELECTION OF NEW MEMBERS, ASSOCIATES, ASSOCIATE MEMBERS, AND GRADUATES.

The President, in calling on the Secretary to read the list of elections and transfers, said the names had been very carefully considered by the Scrutineers Committee, who took their work very seriously and devoted a great deal of time to it. The Council that afternoon had also gone carefully over the names. Any comments which members might desire to make would, however, be welcomed.

The Secretary read the names of the applicants recommended by the Council for election as Members, Associate Members and Graduates.

MEMBERS.

Frederick Joseph Hayden	Frederick Hayden Ltd., 35 High Street, Tunbridge Wells.
Charles Alexander la-Roche Oades	John Drake & Co. (Egham) Ltd., 59 High Street, Egham, Surrey.

TRANSFERS FROM ASSOCIATE MEMBERS TO MEMBERS.

Edward James Allman	"Nynax," Plymyard Avenue, Bromborough, Cheshire.
John Herbert Bryant	47 Fordhook Avenue, Ealing, London, W.5.

ASSOCIATE MEMBERS.

Harold Dudley Barrett	McCann Ltd., Temple Chambers, Temple Street, Dublin, I.F.S.
Oswald Edward Folkes Dye ..	Commonwealth Government Offices, Department of the Interior Engineering Staff, Acton, Canberra, F.C.T., Australia.
George Herbert Fletcher ..	c/o Chief Engineer, Royal Engineers, Scottish Command, Edinburgh.
Michael Jordan	5 Rathfarnham Avenue, Terenure, Co. Dublin, I.F.S.
Kenneth Robert Plowright ..	Gordon & Co. Ltd., 445 Szechuen Road, Shanghai, China.
Basil Anthony Poole	45 Coniscliffe Road, Darlington.

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER.

John Murray Grammer	35c Dartmouth Park Avenue, London, N.W.5.

GRADUATES.

Richard Guy Berrington Crittall..	49 Wickham Way, Beckenham, Kent.
John Gordon Ford	Redlands, Oak Hill, Woodford Green, Essex.

The President said that all those whose names had been read out were good men and true, and he hoped and believed would be a credit to the Institution. He suggested that the members present should express their approval by acclamation.

NOMINATION OF TWO VICE-PRESIDENTS.

The President said he would pass over Item 3 on the Agenda for the moment, and take next Item 4, the nomination of two Vice-Presidents. As would be seen from the Agenda, the Bye-laws provided that the Vice-Presidents " shall be two in number, and shall be chosen from those who are or have been Ordinary Members of Council." The Council had nominated Mr. A. B. Potterton for re-election. There would, he was sure, be general agreement that Mr. Potterton was the right man for the job ; he had given good service on the Council and deserved the step-up to the position of Senior Vice-President, which it was now proposed should be given him. The other name proposed by the Council was that of Mr. C. R. Allensby. Mr. Allensby was well known to most of the members. He was a director of a very well-known and highly esteemed firm in the heating and cooking industry, Messrs. Benham & Sons Ltd. Mr. Allensby had served for some years on the Council, and whatever he undertook was well and truly done ; he did not undertake a job unless he intended to carry it out and to give to it all the time and attention which it required. His advice on the Council and on Committees was invariably sound. It was men of that type who were wanted by the Institution. As some of the members knew, Mr. Benham, unfortunately, did not enjoy very good health, so that a large amount of work in his own business devolved on Mr. Allensby ; but, busy man though he was, Mr. Allensby had an unselfish nature, and was willing to give his spare time when he had any, and time which he ought to give to other things when he had not, for the good of the Institution. Personally, he had no doubt that the members would welcome very heartily the nominations which the Council had made.

The nominations were greeted with acclamation.

Mr. C. R. Allensby, in response, thanked the President for his kind remarks and the Council for the great honour which they had conferred upon him, and which he very much appreciated. No man, indeed, could appreciate the distinction more highly than he did, for it was a step towards the realisation of the highest ambition which any member could have, the Presidency of the Institution ; and he hoped that, if he gave good service as Vice-President, he might attain to that high position in due course. In addition to thanking the Council he would like to thank the members present for the support they had given to his nomination. He would do his best to uphold the great traditions of the Institution.

NOMINATION OF PRESIDENT FOR 1935.

The President, reverting to Item 3 on the Agenda, said he had now to announce the nomination of the President for the year 1935. The Council unanimously, and he himself most heartily and with the greatest confidence, put before the members the name of Mr. W. E. Fretwell. Mr Fretwell was well known to all the members. The great work which he had done for many years on behalf of technical education in the industry had been of enormous value to them all. In spite of the fact that he devoted so much time to educational work, Mr. Fretwell would give up a great deal of time to guiding the Institution during the coming year. The work which he did for the advancement of education was remarkable. He was Chairman of the National Technical Education Committee under the Joint Industrial Council, and also Chairman of the London Education Committee. Personally, speaking as a member of both those Committees, he could give the assurance that Mr. Fretwell's work on both was most thoroughly done. It took up a great deal of time, and Mr. Fretwell took a very great interest in it. The members could be confident that Mr. Fretwell would give as much, or even more, time and interest to the work of the Institution, and he therefore had the greatest pleasure in putting forward his name as President for the ensuing year.

The nomination was ratified by acclamation.

Mr. W. E. Fretwell expressed his gratitude to the members present for the hearty applause with which they had greeted his nomination. The President had referred to some of the activities in which he was engaged. It had been a great pleasure to him to take part in them, and if elected President he could only say that the welfare of the members would be his constant care. He hoped he would be able to maintain the high traditions set by his predecessors, and he looked forward to receiving the loyal support of the members during his year of office.

NOMINATION OF HONORARY TREASURER.

The President said that Mr. W. Nelson Haden had acted as Honorary Treasurer of the Institution for the past twenty-five years. He had recently written to the Institution to say that he would like to be relieved of the office and that, in view of his advancing age, he felt that a younger man should take his place. The Finance

Committee, before whom the question first came, strongly urged him to continue as Treasurer, and personally he was certain that all the members would endorse that view. Everything possible would be done to help him and to lighten his duties. On that understanding, Mr. Haden had consented to act for one more year. The Institution could not possibly have a better Treasurer, and the thanks of the members were due to Mr. Haden for the work he had done during the past twenty-five years and for his great kindness in consenting to serve for another year.

The nomination was greeted with acclamation.

NOMINATION OF MEMBERS OF THE COUNCIL.

The President said the provisions of the Bye-laws with regard to the nomination of Members of Council were set out on the Agenda. The Council had given careful consideration to the matter, and were putting forward six names, as follows :—

Members of Council : Mr. G. Nelson Haden, for re-election ; Mr. E. A. Couzens (Birmingham) and Mr. L. J. Fowler (London), for election.

Associate Members : Mr. W. S. Holt and Mr. J. W. Stitson, for re-election ; Mr. R. E. Otter (Birmingham), for election.

Any Member or Associate Member could add to the list of candidates by delivering within ten days such nomination in writing to the Secretary, together with the written consent of such person to accept office if elected. If no nominations were received within ten days, the six gentlemen whose names he had read out would be the elected members of Council.

APPOINTMENT OF SCRUTINEERS IN CASE OF BALLOT.

The President said it would be necessary to appoint three scrutineers to act in case of a ballot. The scrutineers last year, when a ballot was necessary, were Messrs. R. E. Herring, E. B. Darby and H. J. Knox. They carried out their work very efficiently on that occasion and, if no one wished to suggest other names, he thought the meeting could not do better than elect them again as scrutineers to act in the event of a ballot being necessary.

The proposal was agreed to unanimously.

PRESENTATION OF INSTITUTION PRIZES.

The President said that the next item on the Agenda was a very pleasant one, namely, the presentation of the Institution Prizes awarded by the City and Guilds of London to candidates successful in passing their examinations in Heating and Ventilating Engineers' Work. The following prizes had been awarded :—

Intermediate Examination :—

First Prize —Mr. John Wilfred Holland, Liverpool.

Second Prize—Mr. Donald McMinn Henderson, Birmingham.
Third Prize—Mr. Reginald Charles Tearall, Bournemouth.

Final Examination :—

First Prize—Mr. William Leslie Howe, Nottingham.

The President then, amid applause, handed their prizes to Mr. John Wilfred Holland and Mr. William Leslie Howe, the two prize-winners present. Addressing Mr. Holland, he said it gave him the greatest pleasure to see him present that evening and to hand him his prize. By gaining the First Prize in the Intermediate Examination he had mounted at least one step up the ladder, and he hoped he would go on to win further honours, including perhaps the prize in the Final next year, and would later become a member of the Institution and profit in after life by the tuition he had received. He congratulated him very heartily.

To Mr. Howe he said that to gain the First Prize in the Final Examination was a very high honour, requiring as it did a large amount of study and knowledge. He hoped that Mr. Howe would reach a high position in the industry, which could be done only by devoting time to study. He trusted Mr. Howe's success would be a stepping-stone towards future honours and a great success in his career.

COMMITTEE REPORTS.

The President said that in view of the long and interesting paper by Dr. Taylor which was to follow it was inadvisable to spend much time on the Reports of the various Committees, which could be studied at leisure when they appeared in the *Journal*. There were, however, two Committees whose activities might be mentioned. First of all, the work in connection with the Benevolent Fund.

Benevolent Fund Committee.

The President said the work of this Committee was going on slowly but surely. The matter was now in the hands of the legal experts and the Board of Trade, who had formally to pass the constitution. The wheels of the law ground slowly, but they ground very surely. It would be necessary to wait a little longer before the Benevolent Fund could be started, but it was hoped to announce in the *Journal* very shortly that the Fund was duly constituted. He hoped that all the members would co-operate and become members of the Fund, and wherever possible assist it by donations.

The other Committee about which the members would probably like to hear a few words was the Research Committee, and he would ask Mr. Nobbs to say something of its work.

Research Committee.

Mr. W. W. Nobbs said he was pleased to be able to report that the construction of the new experimental house had now been commenced. The President and himself visited the Research Station at Watford the previous week and found the work in progress ; the foundations and the bottom concrete floor had been laid, and the exterior walls were up to about window-sill height. It was anticipated that the building would be finished, and possibly all the equipment installed, by March next. Much depended, of course, on the time taken to supply and fit up the engineering equipment of the building, as that went hand in hand with the building construction. It would certainly be possible, however, to report definite progress at the February Meeting, and it was hoped at that meeting to submit a programme of the research work with which it was proposed to commence.

Publicity Committee.

Mr. Alcwyn A. Jones reported that the Committee had produced the programme for the Session commencing that evening, with the assistance of the Honorary Secretaries of the Associate Members and Graduates Section, who had to be congratulated on producing such interesting programmes.

It had been found more difficult each year to secure papers for the meetings owing to the diffidence on the part of the members to offer papers. In a growing Institution that should not be so, and unless the members began to realise that they owed something to their Institution there would be no papers to be read at the meetings.

The papers read at the Associate Members and Graduates Section meetings had again been considered by the Committee and the Council had decided to award bronze medals to Mr. S. F. Greenland (Associate Member) for his paper on " Practical Determination of Heat Transmission from Buildings," and Mr. F. R. L. White (Associate Member) for his paper on " Domestic Hot Water Supply for Large Buildings."

Dr. F. M. H. Taylor, Ph.D., B.Sc., A.R.C.S., A.I.C. (Member), then presented and gave a summary of his paper entitled " Some Recent Improvements in Boiler Plant for Central Heating and Hot-Water Supply," illustrating it by a number of lantern slides.

SOME RECENT IMPROVEMENTS IN BOILER PLANT FOR CENTRAL-HEATING AND HOT-WATER SUPPLY

By F. M. H. TAYLOR, Ph.D., B.Sc., A.R.C.S., M.Inst.Fuel. (Member).

AUTUMN SPECIAL MEETING, LONDON, OCTOBER 9th, 1934

GENERALLY the improvements in boiler plant have taken place by :—

1. The development of automatic control, giving higher system efficiency as well as a reduction in labour.
2. Improvement of the actual combustion efficiency in boilers by automatic feeding, again resulting in fuel economy and reduction in labour.
3. Improved methods of control of the operation and supervision of central-heating plant.

The types of boiler plant considered in this paper are those using coke, coal and gas. These particular fuels have been chosen because the improvements described relate mainly to the past two years, and it is here that the chief recent advances have been made.

Coke boilers have been given greater prominence not because of any special claims for this system of heating, but because the Institution would naturally expect the author to give more complete details of the work with which he has been so closely associated during the last few years, and on which he can speak with greater authority.

The external equipment of boilers, particularly automatic control, has been described in detail, since their fitment to the hand-regulated type of boiler has led to very marked improvements in the operating efficiency.

AUTOMATIC CONTROL.

Automatic control of the hand-fed boiler was introduced because competition with gas- and oil-firing, thermostatically controlled, made economy and the avoidance of overheating a necessity. The need for constant attention meant relatively high labour costs, and this has been considerably reduced by thermostatic operation.

The Natural-Draught System for Central Heating.

The system for natural draught consists of the regulation of the air supply to the grate through the operation of the flue, check-draught and primary air dampers, by means of a fractional

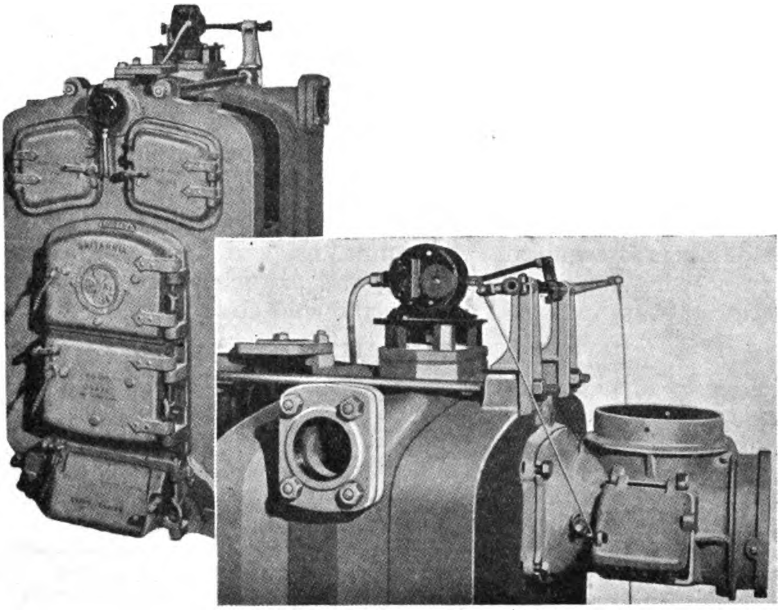


Fig. 1. The fitment of Natural-Draught Thermostatic Control to a typical Sectional Heating Boiler.

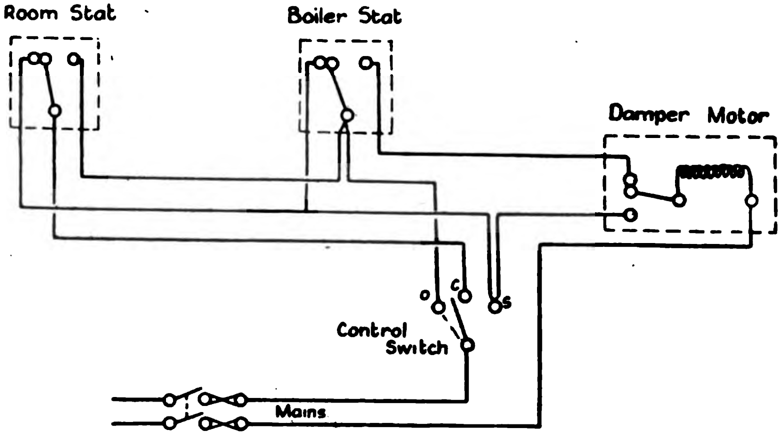


Fig. 2. Wiring Diagram for a simple Thermostatic Control System of Room and Boiler Thermostats and Damper-Operating Motor.

horsepower motor. This motor, (Fig. 1) is controlled by a room thermostat on an upper floor and in addition a boiler thermostat is provided on the boiler flow-pipe in order to limit the temperature to that to which the boiler may be raised with safety. The boiler thermostat takes precedence over the room control, ensuring that the boiler temperature cannot in any circumstances exceed a figure consistent with safety. Any increase or decrease in the building temperature is communicated to the motor, which opens or shuts the dampers as required. As seen in Figs. 2 and 3, a double circuit may be wired to the thermostats, and to the motor. When both thermostats are in a cold position the cold circuit is made and the motor is put into operation, thus opening the dampers. After half a revolution a switch fitted to the motor is automatically broken, and at the same time the second or hot circuit is made in the motor. The circuit is not completed, however, until one of the thermostats also makes a hot contact, and the motor is again put into operation and closes the dampers. At the end of the half revolution the circuit is broken and the cold circuit made, so that the cycle may be repeated. The arrangement of thermostats is such that both thermostats must be in the cold position before the dampers can open, but either thermostat on the hot circuit is sufficient to close the dampers. A hand-control switch is wired also in conjunction with the thermostats to open or close the dampers at will, a provision, however, being made that if the boiler water temperature exceeds a given figure, it is impossible to open the dampers by the hand switch. The type of thermostat used is normally the bi-metallic strip type, the same as that used on electrical and oil-fired installations. Fig. 4 shows the variation of temperatures with and without thermostatic control.

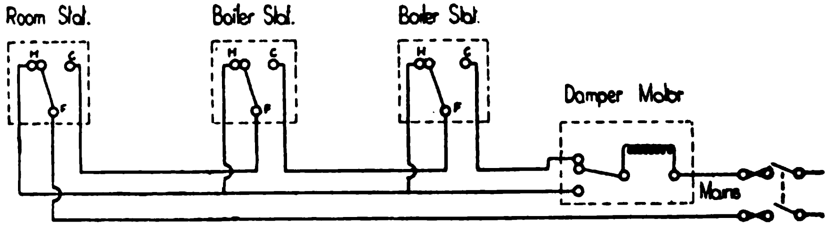


FIG. 3. METHOD OF WIRING ADDITIONAL BOILER THERMOSTATS OR HAND-OPERATED SWITCHES WHEN TWO OR MORE BOILERS ARE EMPLOYED.

Mechanical Details.—The arrangement and adjustment of levers (Fig. 5) is of great importance to the successful fitment of control

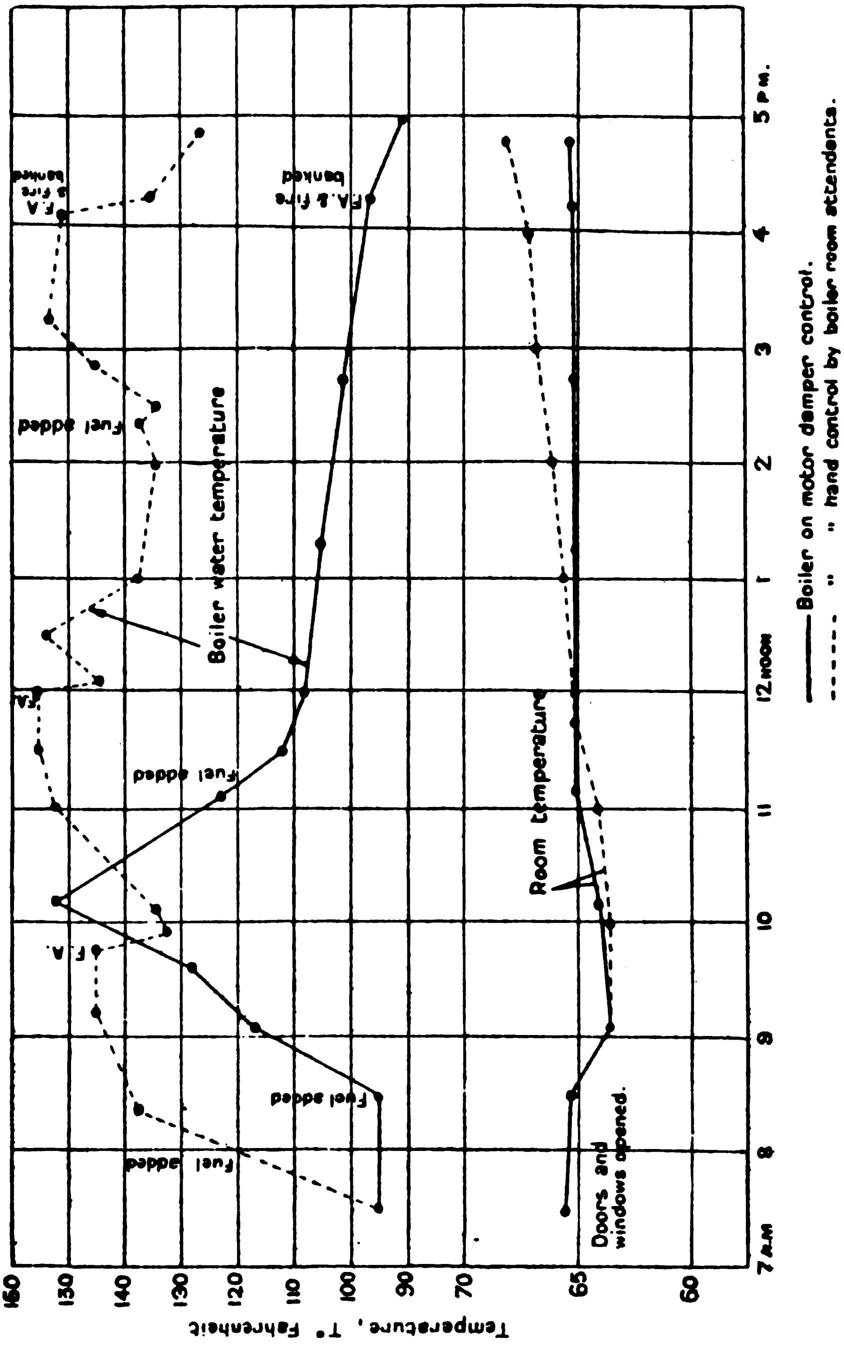


FIG. 4. RECORD OF ROOM AND WATER TEMPERATURES AND OF STOKING ATTENTION FOR A HAND-FIRED SECTIONAL BOILER, WITH AND WITHOUT THERMOSTATIC CONTROL.

systems where very light motors have to handle heavy dampers. The lengths of the various crank arms rotating on the main operating shaft determine the distance which the respective dampers may be opened, and allow the requisite adjustments to be made.

Costs.—The cost of thermostatic control of necessity varies greatly according to the type of system used, and the extent of control obtained. As a guide, it may be taken that a fairly simple control for a coke-fired sectional boiler, consisting of a room or calorifier thermostat, boiler thermostat, damper motor and mechanical fittings, will cost about £25 to £35, with an extra £8 to £10 for each additional boiler working in parallel.

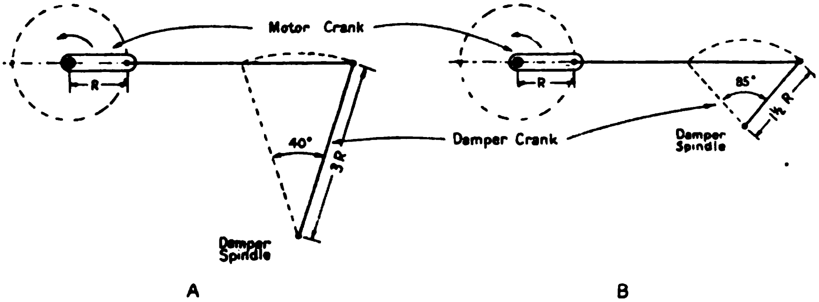


FIG. 5. SHOWING HOW THE CRANK ARMS OF CONTROL EQUIPMENT MAY BE ADJUSTED TO GIVE VARYING DAMPER MOVEMENTS AS REQUIRED.

Applications of Thermostatic Equipment.

Various devices for mixing may be controlled by the thermostat or by a variostat, whereas motorised and magnetic valves in the water flow, or pressure-operated valves are controlled by the room thermostat, allowing zoning of a building, or individual-room controls where required. This does not affect the principle of control of the boiler by the boiler thermostat, as a diminution of the heat requirements of the building results in a tendency for the boiler water temperature to rise, resulting in operation of the boiler thermostat, thus closing the boiler dampers until equilibrium is regained.

The standard systems of automatic control are suitable for use with special heating systems such as the Thrush system, in which the circulation of hot water to radiators is regulated according to the heat demand.

Dual Systems.

For combined heating and hot-water supply systems (Fig. 6) the room thermostat operates a motorised, magnetic or similar type of valve on the heating circuit, while an immersion thermostat controls the boiler water flow to a constant temperature, usually 160° or 180° F. Hot-water supply is obtained through a calorifier, heated by the boiler water. This gives adequate control of the hot-water temperature, which in practice remains approximately 10° F. below the boiler water temperature.

The central heating of combined systems is controlled by a motorised or magnetic valve, either directly, on the heating flow or in a by-pass to the main heating system so that cool return water can be mixed with the hot flow from the boiler to give the correct temperature required to supply the requisite heat to the building. In cold weather hot water will be supplied almost direct from the boiler. In mild weather the by-pass would be opened and the greater part of the water circulated in the system would be relatively cool return water.

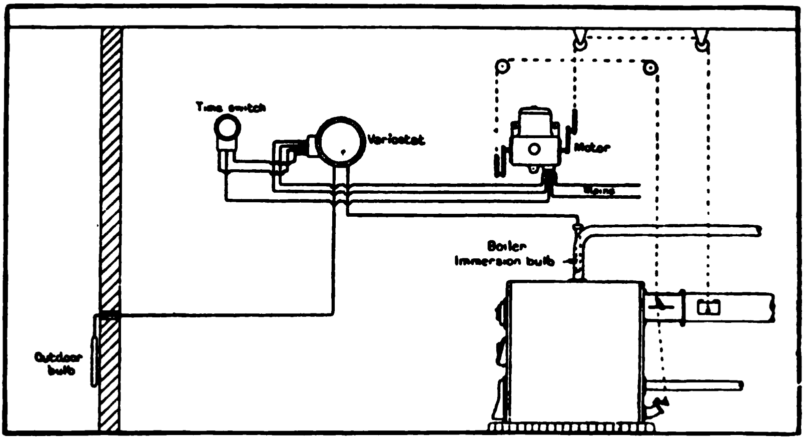


FIG. 6. DAMPER-OPERATING MOTOR CONTROLLED BY A VARIOSTAT WITH WATER IMMERSION AND OUTSIDE BULBS TO REPLACE ROOM THERMOSTAT. TIME SWITCH GIVES DAY AND NIGHT TEMPERATURES.

As will be seen from Fig. 7, the motorised valve circuit may be so wired that the calorifier thermostat exerts a master control on the motorised valve and closes the heating circuits should the calorifier temperature fall below the prescribed limit. The system reverts to room thermostat control as soon as the hot-water temperature is regained.

Circulation in Dual Systems.

A circulation device which is of great value in existing heating systems to which thermostatic control is applied, and where it is wished to employ only one circulating pump, and at the same time ensure circulation of hot water to the calorifier as well as to the heating system, has been carried out by means of a venturi tube, the orifice of which was designed to give a pull of approximately 11 in. w.g. This figure can be readily calculated by the application of Bernoulli's theorem, which states that in any stream line flow of water the total energy possessed by any point in the flow is constant.

Expressed in symbols this reads :—

$$\frac{v_2^2 - v_1^2}{2g} = H_1 - H_2$$

where H_1 is the pressure energy expressed in feet head, and $\frac{v^2}{2g}$ is the kinetic energy, or energy due to velocity. Therefore as the flow through the venturi is constant, the velocity at the throat is considerably in excess of that at the inlet. This increases the velocity energy at the throat, and accordingly reduces the pressure energy, causing a relative suction at that point. At the normal pump speed, the velocity in the main pipe is approximately 0.5 ft. per second, and the velocity in the throat of the venturi approximately 7.8 ft. per second. As shown in Fig. 8, this suction gives positive circulation through the calorifier without the employment of a separate pump.

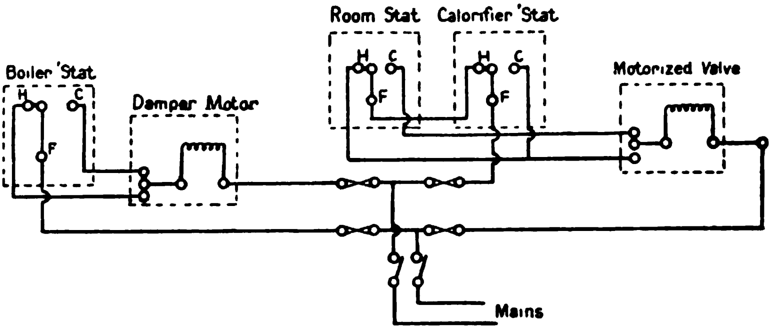
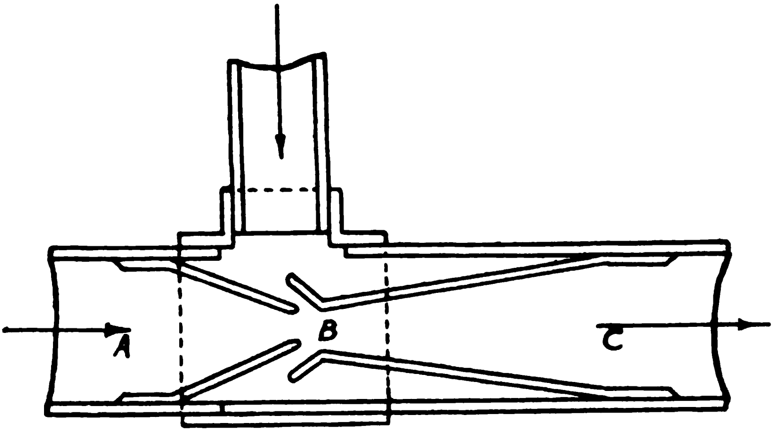


FIG. 7. DUAL SYSTEM SHOWING MOTORISED DAMPER CONTROL WITH ROOM-CONTROLLED MOTORISED VALVE AND A CALORIFIER THERMOSTAT TO CUT OUT THE CENTRAL HEATING UNTIL THE HOT-WATER SUPPLY IS REPLETE.

The Self-Acting Thermostat.

For small domestic boilers the dampers can be operated by a self-acting thermostat placed in the flow-pipe, thus keeping the boiler water temperature constant. This thermostat may be of the metallic-rod type, or an expanding liquid, or more usually of the pressure-bellows type, depending for its action on the vapour pressure of a liquid of low boiling-point, the pressure varying with small fluctuations in the temperature.

The power generated by these instruments is very high, but the movement is small and the large magnification required greatly reduces their efficiency, and satisfactory operation can only be obtained when the installation is carefully balanced.



Total pressure at A - 70' Head
" " " B - 69'-1" "
" " " C - 70' "

FIG. 8. VENTURI TUBES WITH STATIC PRESSURES ILLUSTRATING THE METHOD OF INDUCING CIRCULATION IN SYSTEMS TO WHICH DUAL CONTROL SYSTEMS ARE APPLIED.

A type, recently introduced, is packed with paste having a very high coefficient of expansion. These develop an extraordinarily high power, and have brought the fitment of controls within the range of the household boiler. They are powerful enough to overcome defects in damper fitment. One of the advantages of thermostats has been that boilers which previously gave trouble through burning-out or extinguishing overnight can be maintained alight at low output for the whole period.

Careful experiments on the control of boilers by self-acting thermostats have led to the conclusion that the check-draught damper gives the most satisfactory operation. Special large check-draught dampers are fitted and in certain instances a combined check-draught and butterfly flue damper is used. Control of primary air dampers is not advised, as the operating gear interferes with normal stoking operations.

Room Control.—Fairly accurate room control may be obtained by radiator or heating circuit valves, operated in conjunction with self-acting thermostats. Their description is considered to come outside the scope of this paper.

The Forced-Draught System.

Where increased boiler output is desired, or sudden demands are anticipated, forced draught is provided by means of a fan which is started and stopped by the room thermostat and boiler limit thermostat. The wiring is much more simplified, being a single circuit.

Forced draught allows small fuels, such as breeze and small coals, having a high fuel-bed resistance to the passage of air, to be burned in central-heating boilers. Special small firebars are necessary when using these fuels, and these are usually supplied with proprietary makes of forced-draught apparatus. With coke the ordinary standard firebars may be retained.

One disadvantage of forced-draught equipment fitted to sectional boilers is that air leaks occur between sections, so that a certain quantity of air is drawn in by natural draught even when the fan is shut down. This, of course, leads to a continued combustion of fuel and to serious overheating when the boiler is on low load. Where the welded-steel boiler is employed this disadvantage does not apply, and several such installations have been successfully equipped. When small graded fuels are used the resistance of the fuel-bed is greater and this leakage when the fire is shut-off is reduced to negligible proportions.

Secondary air adjustment with forced-draught equipment is by no means simple. Usually, except with stokers, no provision is made for introducing forced secondary air over the fuel-bed to burn off volatile matter and any carbon monoxide formed by secondary reduction of the carbon dioxide.

Auxiliary Thermostatic Controls.—Just as in the natural-draught systems all types of secondary controls may be fitted to a heating system when the boiler is on forced-draught control. The circuits and general arrangements are much simpler.

Types of Thermostats.

The success, and more particularly the reliability of automatic-control systems depends so largely on the thermostat or pressurestat itself that a consideration of the main types may not be inappropriate.

The most delicate types may be used on natural-draught controls because the circuit is so arranged that the current is always broken on a switch in the motor and the thermostat merely makes the contact, and arcing is reduced to a minimum. This, coupled with the very small power required to operate the motor means that a light thermostat may be used—one which is sensitive to ± 1.5° F.

Electrical thermostats may be divided into two main groups :—

(*a*) Vapour pressure.
(*b*) Bi-metal.

Each of these may be again divided into two groups according to the type of switch, i.e. :

1. Mercury switch.
2. Metallic contact.

As a general rule, the vapour-pressure thermostats are fitted with mercury switches, and the bi-metal type are fitted with silver-alloy contacts. In order to obtain a snap action of the switch and reduce arcing to a minimum, mercury switches are usually connected to the vapour-pressure bellows by a spring-loaded toggle linkage. In bi-metal thermostats the moving contact is fitted with a small piece of soft iron and a very small permanent magnet is placed behind the fixed contact, thus giving a magnetic bias to the element which requires a definite rise or fall of temperature before the stress set up by the bi-metal element is sufficient to break contact on one circuit and ensure a positive make on the other.

Thermostats in which the bi-metal element carries the current under control may be those intended to control very small intermittent currents or those controlling larger continuous currents such as fans and driving motors. Those for small currents are usually employed to control damper-operating motors or motorised valves, etc., in which the current to be carried by the thermostat is sufficiently low and of such a short duration that there is no appreciable heating of the bi-metal element, and thus no risk of a false temperature reading. It is better, as a general rule, to control large or continuous currents through a relay, thus enabling the thermostat to be made considerably lighter in construction, and more sensitive to small temperature changes.

Most of the vapour-pressure type thermostats can be readily adapted to deal with direct steam pressure for the control of low-pressure heating boilers or high-pressure industrial steam boilers as easily as for temperature.

Safety Switches.

It will be appreciated that some means of automatically closing the boiler dampers in the event of failure of the electric supply is necessary. With this need in view an electro-mechanical safety device (Fig. 9), has been developed. The general principles of operation are as follows : The pulling motor is connected to the dampers by means of cranks and links, and this coupling is arranged to be instantaneously disconnected in the event of power failure, thus allowing the dampers to close, due to their own weight or, if need be, a counterbalance weight. On the resumption of the supply the motor immediately moves to the closed damper position and picks up the damper gear again. It then remains closed or reopens in accordance with the setting of the thermostats. The connecting rod between the motor crank and the main crankshaft is of the telescopic type, the closed length being equal to the normal connecting rod, and the extended length being equal to the connecting rod length plus twice the radius of the motor crank. The telescopic connecting rod is normally held in the closed position by means of a small locking pin, which in turn is held in position by an electro-magnet or solenoid. When all the power is switched-off and the electro-magnet is de-energised the locking pin is disengaged and the connecting rod thus free to extend. Immediately the power is switched-on, the electro-magnet becomes energised, the pin is driven home into position, locking the two parts of the rod together, and the whole unit acts as a normal solid connecting rod. Coupled to this rod is a small mercury switch, which is so connected into the control circuit that when the connecting rod extends, the switch contacts are made and short circuit the closed damper positions of the thermostats, thus ensuring that as soon as the power is switched-on the motor will turn into the closed damper position, if not already there. The normal movement of the connecting rod when operated by the motor, however, is not sufficient to throw this switch over. It thus remains inoperative unless the current fails.

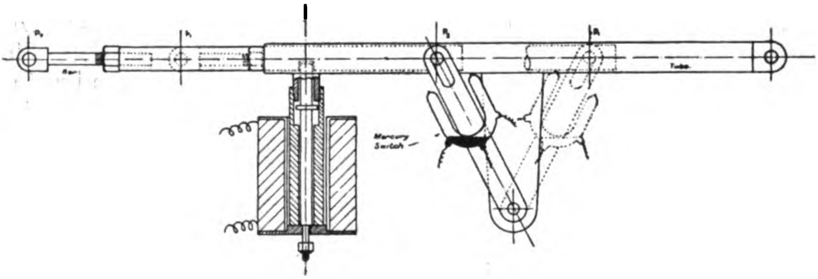


FIG. 9. SAFETY DEVICE FOR AUTOMATIC CONTROLS SHOWING THE CONNECTING PIN HELD BY AN ELECTRO-MAGNET WHICH FALLS ON CURRENT FAILURE. THE SWITCH ENABLES THE PIN TO RE-ENGAGE AUTOMATICALLY ON RESUMPTION OF THE ELECTRIC SUPPLY.

An alternative arrangement uses two cranks side by side on the main crankshaft, one of which is locked to the crankshaft in the normal way, the other being free to rotate. The two are locked by a similar electro-magnetically controlled pin.

In either arrangement the electro-magnet is arranged to operate the bolt from the locking pin with a hammer action, thus obtaining the necessary force to overcome inertia and initial friction. The device may be arranged to function each time the thermostat comes over to the closed damper position, thus testing itself automatically at each operation of the motor.

Developments in Automatic Control.

The Compensating Thermostat.—A thermostat for insertion in the boiler or flow-pipe consists of a bi-metal spiral, fixed at its outer end. The inner end is attached to one of the crown wheels of an epicyclic mechanism, the other crown wheel carrying an arm which is attached by means of suitable connecting rods to the link mechanism between the operating motor and the boiler dampers. The intermediate pinions between the two crown wheels carry the switch which controls the motor.

When the temperature changes, the bi-metal element rotates the inner crown wheel and thereby moves the switch. This causes the damper motor to start and move the dampers, which in turn cause the outer crown wheel to rotate in the reverse direction, and this returns the switch to its neutral position and stops the motor. Thus the temperature at which the thermostat will next time cut in or out is automatically reduced. The net result of this action over a series of movements is to flatten out the differential fluctuations in the boiler water temperature, and after half an hour's operation a straight line temperature chart is obtained.

Self-closing Damper Motor.—The motor, which may be used independently or in conjunction with the compensating thermostat is also of novel design. It operates a crank via the necessary reduction gearing and a centrifugal clutch. When the thermostat switch makes contact the motor starts and the clutch is engaged by centrifugal action and moves the crank through about 60-90°. As soon as the desired movement is reached a mechanical switch, operated by the gearing breaks the motor circuit, thus stopping the motor and disengaging the centrifugal clutch. As soon as this has occurred the crank is free to move back to its original position, due to the weight of the dampers, the speed at which this returns being governed by means of an eddy-current brake, driven by the gearing, the braking force and rate of closing being adjustable by variation of the distance between the disc and magnets.

The advantage of this type of motor is that since the dampers begin to close automatically immediately after opening should power failure occur at any time the dampers will automatically close and remain closed irrespective of their positions or the position of the thermostats at the time the supply fails. At the moment its size, weight, and cost are such that it is only justified on very large installations.

Hydraulic Thruster.—Another type of power unit which is very suitable where comparatively large powers are required, consists of a small electric motor, direct-coupled to a small centrifugal pump, the motor and pump being mounted in a single casing, the outside of which is formed as a hydraulic cylinder complete with ram.

On completion of the electrical circuit, by means of a thermostat or switch, the motor starts up driving the pump, which forces oil from a self-contained reservoir into the hydraulic cylinder, thus forcing the ram out. The power developed is considerable, and the return movement can be controlled by an adjustable valve between the pump and the cylinder. Its disadvantage, however, is in the fact that the motor must be kept running continuously in order to hold the ram in the " out " position, and though designed to withstand what is virtually a stalled load with comparatively low power consumption, it is nevertheless a disadvantage.

Thermal Motor.—Another small power motor unit which is manufactured in America operates on the " thermal motor " principle. A low voltage, low temperature, electric heating element is inserted in a chamber containing a volatile liquid. When the thermostat makes circuit to the element, the heat vaporises some of the liquid, increasing the internal pressure, forcing the liquid through a connecting tube which runs from the bottom of the heating chamber to the bellows chamber. Opposing the bellows is a spring, which normally keeps the fire checked. The pressure of the vapour against the head of the bellows overcomes the spring, which is forced upward on the stem and opens the draught. When the thermostat breaks circuit the motor unit operates in the reverse manner, checking the draught.

The Maintenance of Controls.

Automatic equipment of any description is of no use to the client unless it is of the utmost reliability. Thermostatic control installations so far fitted by the author have worked with a very high degree of reliability over a period of more than two years, but in order to obtain optimum results a few necessary adjustments, greasing, etc., should be carried out at regular intervals. For this reason a maintenance scheme has been instituted whereby central-heating plant is visited once at the beginning of the heating season for cleaning, adjustment, greasing and general overhaul, and hot-water systems twice per annum. This gives a further degree of confidence to the client, and the whole scheme has in fact proved most acceptable.

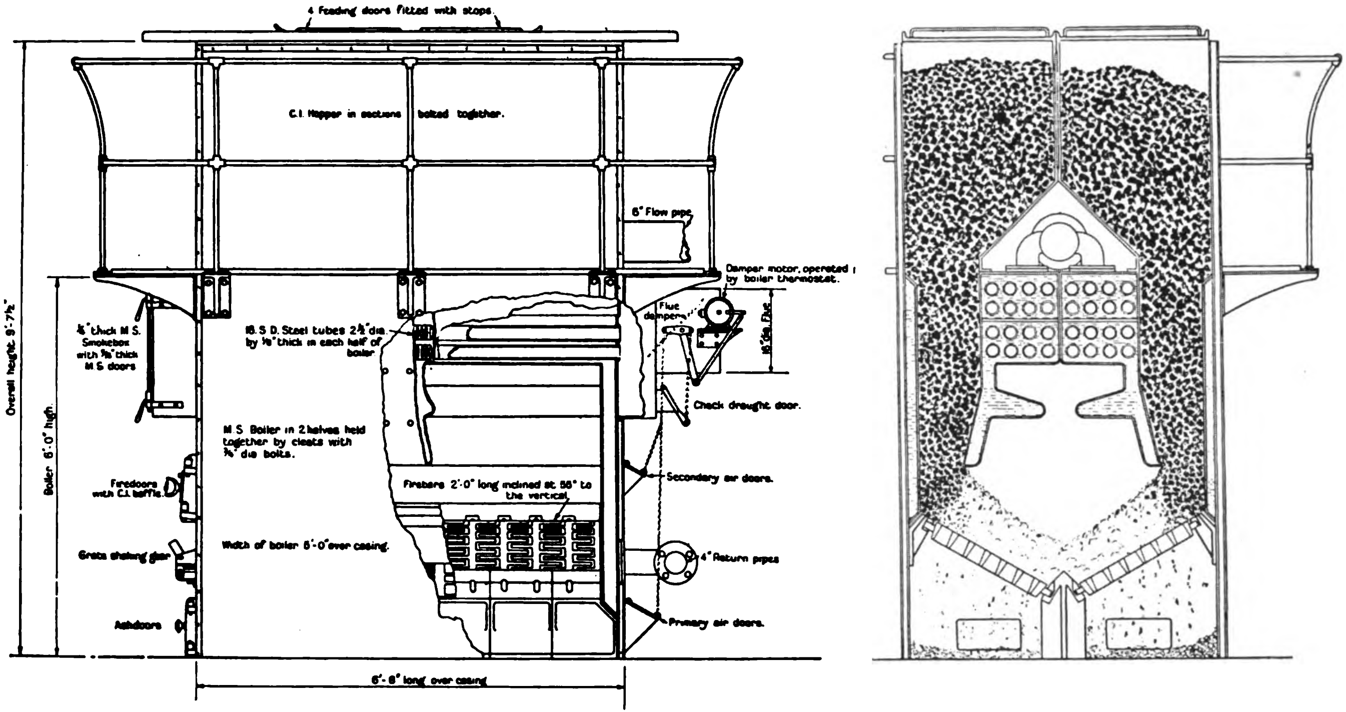

4 Feeding doors fitted with stops.
C.I. Hopper in sections bolted together.
6" Flow pipe
Damper motor, operated by boiler thermostat.
Flue damper
16" dia. Flue
Check draught door.
Secondary air doors.
4" Return pipes
Primary air doors.
16 S.D. Steel tubes 2½" dia. by ⅛" thick in each half of boiler
M.S. Boiler in 2 halves held together by cleats with ⅜" dia bolts.
Firebars 2'-0" long inclined at 58° to the vertical
Width of boiler 5'-0" over casing.
¼" thick M.S. Smokebox with 5/16" thick M.S doors
Firedoors with C.I. baffle.
Grate shaking gear
Ashdoors
Overall height 9'-7½"
Boiler 6'-0" high.
6'-8" long over casing

FIG. 10. ELEVATIONS OF HOPPER-FED BOILER WITH PART VIEW OF TUBES AND GRATE BARS. THE DAMPER-OPERATION GEAR IS SHOWN. (BY COURTESY OF MESSRS. HARTLEY & SUGDEN LTD., HALIFAX.)

Advantages of Thermostatic Controls.

The fitment of thermostatic control to boilers has brought a great many advantages. Automatic control has usually meant a reduction in fuel consumption of 15 per cent., and in some cases much more. It has increased the efficiency of hot-water heating since both underheating and overheating of an effectively designed system can easily be avoided. A reduction of the amount of labour and attention—an important factor for both small and large boilers, has been effected, and the formation of clinker and boiler scale has been greatly reduced. Overheating of the boiler may now be entirely eliminated and the safety of the installation thus materially increased. This has been recognised by the leading insurance companies.

Automatic control is the half-way house towards automatic firing with solid fuels, and the establishment of thermostatic control systems emphasised the need for automatic firing. The simplicity of gravity feeding has led to concentration of this method for coke fuel.

Gravity feeding has, of course, been practised for several years in this country and the United States, and any novel features described refer to the details rather than the principle of the apparatus evolved.

THE GRAVITY-FED COKE BOILER.

The new gravity-fed coke boiler (Figs. 10 and 11) has been designed to provide a means of central heating and central hot-water supply that is automatic, economical, and space saving, without the complication and expense of fans, motors, and other moving parts. Both charging and ash removal are carried out with complete absence of noise and dust, and the clean appearance of the exterior is as striking as the internal design.

The boiler is charged automatically by gravity from its magazine, which is filled daily from the storage hopper by means of the charging lever. De-ashing need only be carried out on alternate days, and the total labour involved amounts to less than one hour per day. Thereafter the boiler can be ignored until the following morning.

By means of the " V "-shaped grate and the gravity feed the fuel-bed depth is kept constant under all conditions. This depth is that found to be most efficient for the particular fuel in use. A 6 in.-8 in. depth of fuel is allowed for burning coke of from 1¼ in. to 3 in. size. The shrinkage of burning fuel allows more coke to be charged automatically from the magazine, so that the fuel is fed in accordance with the rate at which it is burnt. By this method coke is fed, a little at a time, and the gases are completely burnt, in contrast with the common hand-firing practice of covering the

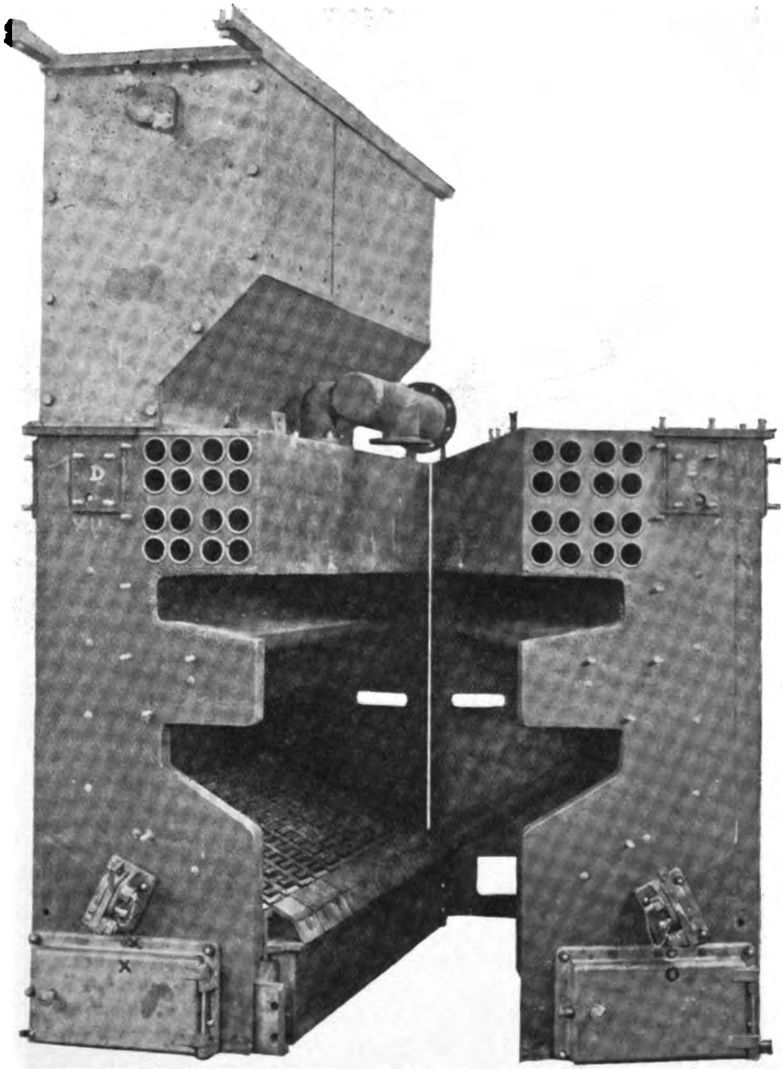


Fig. 11. Constructional view of Hopper-Fed Boiler.

fire with heavy charges of cold fuel, causing intermittent heating and inevitable losses in efficiency.

The Installation of the Hopper-Fed Boiler.

The photograph (Fig 12) of the Imperial College boiler-house shows the position of the boiler in relation to the coke storage hoppers. These are of mild-steel construction, and hold two to

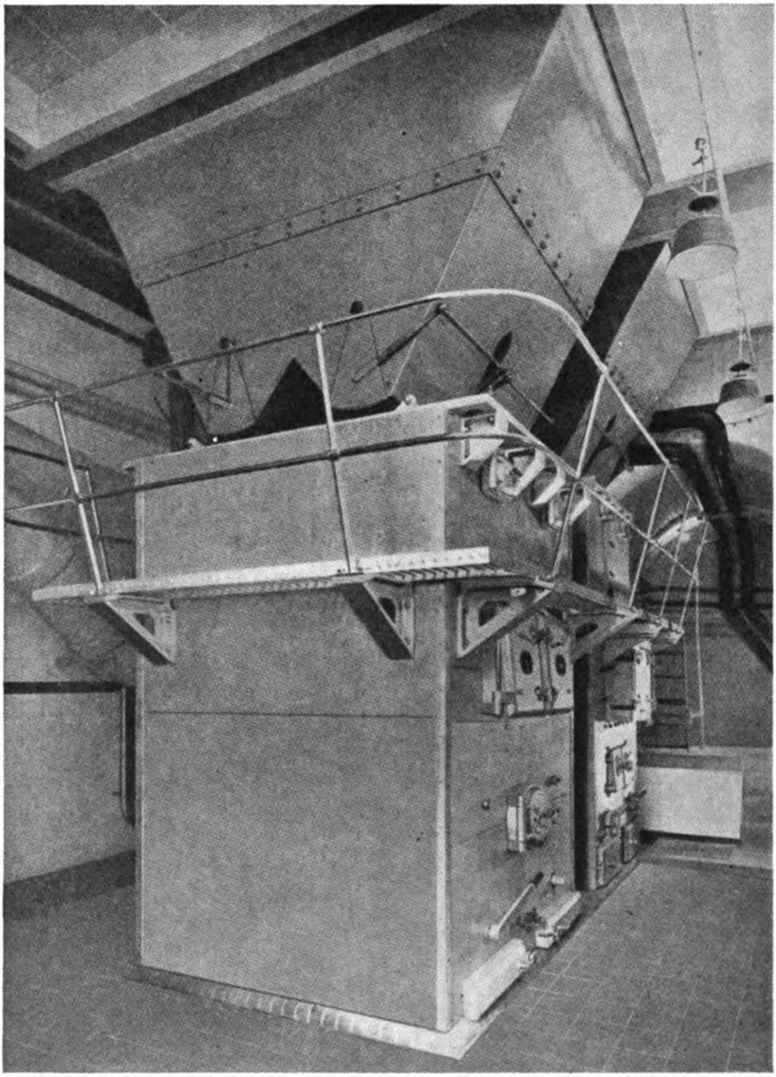


FIG. 12. PHOTOGRAPH OF HOPPER-FED BOILER INSTALLED AT THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, LONDON, SHOWING ELEVATED COKE-STORAGE HOPPERS.

three tons of fuel for each boiler, or approximately four days' supply. They are filled from small openings at pavement level, and coke is transferred by gravity to the boiler magazine by the operation of the guillotine valves, a proceeding carried out once each 24 hours.

An alternative method of feed, shown in Fig. 13, consists of a false concrete roof to the boiler-house about three feet above the boiler. Coke is stored on top of this structure, which may be at pavement level, or preferably six to seven feet below. Guillotine valves are let into the roof above each boiler magazine charging door, and a supply of coke transferred once each day in the usual manner.

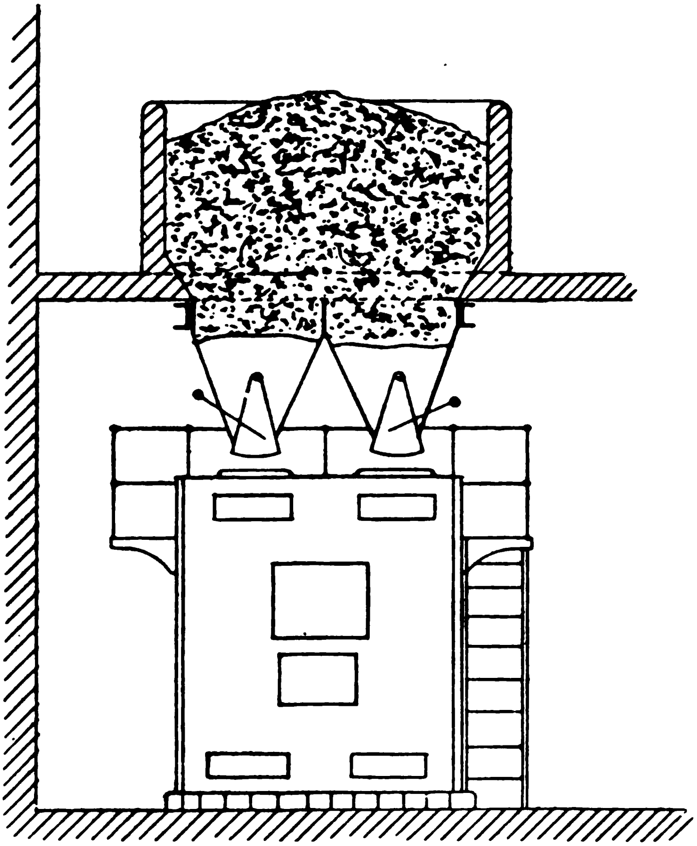


FIG. 13. ALTERNATIVE ARRANGEMENT OF COKE-STORAGE HOPPERS SHOWING A FALSE ROOF OVER THE MAIN BOILER ROOM HOLDING THE COKE SUPPLIES WHICH ARE DELIVERED TO THE BOILER MAGAZINE THROUGH SPECIALLY FITTED GUILLOTINE VALVES.

Boiler Operation.

Since the control of the air is automatic, and the fuel feeds as it burns away, there is no further necessity for regulation of the fuel feed. As long as the correct thickness of fuel-bed is maintained efficient combustion takes place irrespective of the output of the boiler.

After the boiler is first started up the secondary-air doors have to be adjusted by flue-gas analysis to ensure that the correct proportion is provided and both the open and shut positions of the dampers are determined. Once the two positions are decided the automatic damper-operating mechanism ensures that they are maintained throughout the boiler operation.

Interesting results have been obtained on the output of the boiler over a 24-hour period. While it is not usually necessary to operate a heating boiler for 24 hours at maximum output it has been found that the full rated output can be maintained without difficulty. Clinker forms gradually during this period, but some hours elapse before its formation has any considerable effect on the output of the boiler.

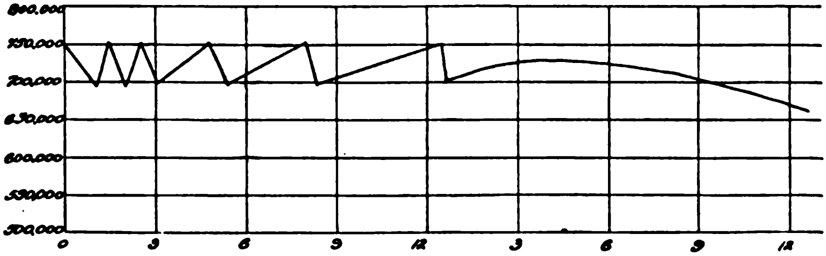


FIG. 14. ADJUSTMENT OF FLUE PULL AND THERMOSTAT SETTING OF HOPPER-FED BOILER TO MAINTAIN THE BOILER OUTPUT OVER A 24-HOUR PERIOD WITHOUT ATTENTION.

The draught once adjusted is maintained at a constant reading by means of a stabiliser fitted in the chimney, so regulated that the boiler output with the dampers fully opened is just in excess of the rated output of the boiler, overheating of the boiler being prevented by the operation of the damper mechanism which closes the dampers for a period of, say, 5 minutes in every 20. If ash accumulation occurs, tending to limit the output, the boiler still maintains its rating because the damper-closing period is reduced, until finally the dampers remain open for the whole of the time. Then, and only then, does the boiler rating gradually fall off. This method of operation is illustrated in Fig. 14, which shows the 24-hour output of a $\frac{3}{4}$ million boiler.

A typical analysis of flue gases for correct damper adjustment is given :—

750,000 B.T.U. Boiler at the Imperial College of Science and Technology.		
Dampers open	CO_2	15.8
	O_2	5.0
	CO	—
Dampers closed	CO_2	14.0
	O_2	5.9
	CO	0.5
Dampers open	CO_2	15.4
	O_2	5.2
	CO	—

The stack losses with a flue temperature of 500° F. (a temperature higher than that reached in practice) amount to 10.6 per cent. and an overall boiler efficiency of 77.4 per cent. may be obtained.

The boiler has operated successfully with a flue pull of 0.14 in. w.g. at the base of the stack. This low pull was made possible by the very low flue resistance and the relatively low resistance of the thin fuel-bed always maintained by the particular type of construction.

Tests undertaken to ensure that the boiler was capable of maintaining even operation under varying climatic conditions, and particularly on low ratings, showed that the boiler can be conveniently banked for twelve hours with the dampers closed, and with a pull of 0.01 in. w.g. at the back smokebox, this reduction in pull being due partly to the low flue temperature and partly to closing the main flue damper.

The average output of a one million B.T.U. boiler during the test was 150,000 B.T.U. per hour, or 15 per cent. of the full rated capacity of the boiler. This gives a much higher degree of flexibility than is required in practice. If necessary the boiler may be operated on half the grate alone, when this minimum rating could be further reduced by half.

Boiler Sizes.

The size of three boiler ratings, for example, are given in the following table. The storage allowed is 18 hours, at full maximum output, which corresponds to 30 hours normal operation during a cold daily period.

B.T.U. per hour.	Width.		Height.		Depth.		Grate Area.
	ft.	in.	ft.	in.	ft.	in.	sq. ft.
1,000,000	5	7	7	0	5	8	23
1,250,000	6	10	7	9	6	2	29
1,500,000	6	10	7	9	7	2	35

The fact that valuable floor space is unnecessary for fuel storage enables large economies in space to be effected in new buildings and allows the installation of this type of boiler where alternative systems are out of the question.

Theoretical Aspects Governing the Design of the Hopper-Fed Boiler.

The efficient operation of the hopper-fed boiler depends on :—

1. The combustion efficiency of the fuel, that is complete combustion of the fuel must be effected by the admitted air, and at the same time the admission of cold air must be avoided.
2. The maintenance of a high efficiency of radiant heat transfer both from the fuel-bed and from the hot flue gases issuing from the fuel-bed.
3. A high efficiency of convected heat transfer.
4. The efficient control of combustion and the avoidance of overheating and wasted fuel.
5. The reduction to a minimum of boiler radiation losses and losses due to unburnt fuel in the ashes.

Combustion Efficiency.—The combustion efficiency is at its highest when the carbon, the main constituent in coke, is completely converted to carbon dioxide, when hydrogen is converted to water, and hydrocarbons to carbon dioxide and water. Of these reactions the conversion of carbon to carbon dioxide in its entirety is of paramount importance. Thus a coke with the following ultimate analysis :—

Carbon by weight	88.0 per cent.
Hydrogen	0.2 ,,
Nitrogen	2.0 ,,
Sulphur	1.0 ,,
Ash	5.8 ,,
Moisture	3.0 ,,

should give a flue-gas analysis of :—

CO_2	19.7 ,,
N_2	80.2 ,,
SO_2	0.1 ,,

by volume, assuming complete combustion with exactly the correct proportion of air. It need hardly be pointed out that the design and operation of the boiler is directed towards obtaining these theoretical values for the flue-gas analysis.

A study of the relevant factors shows that the combustion efficiency depends almost entirely on two main considerations :—

(*a*) The depth of fuel in the grate.
(*b*) The size of fuel.

and to a much smaller extent on :—

(*c*) The reactivity of the fuel.

(*d*) The temperature of the fuel bed.

(*e*) The rate of combustion.

The Fuel-Bed Depth.—Figs. 15 and 16 show the effect of the thickness of fuel on the flue gases obtained from a coke fire. Tests have shown that from a very thin bed of fuel up to a thickness of between 4 in. and 10 in. depending on the size of the fuel, the carbon dioxide figure steadily increases until it reaches a maximum of between 16 and 20 per cent., the carbon monoxide and oxygen percentage being then negligible.

The simple reactions taking place are :—

$$C + O_2 = CO_2 = 14{,}590 \text{ B.T.U. per lb.}$$
$$2H_2 + O_2 = 2H_2O$$

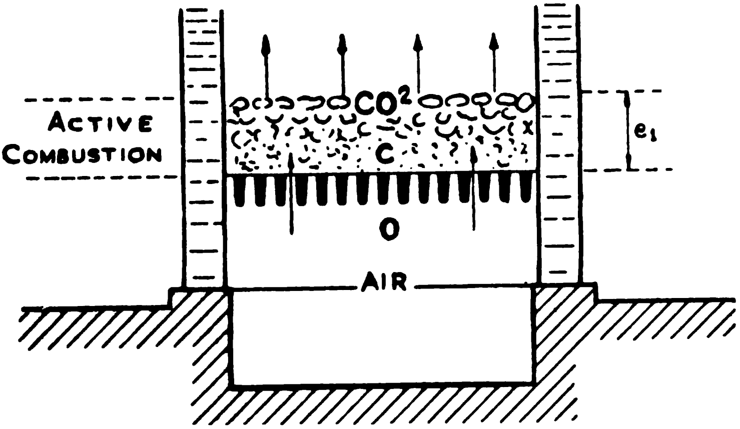


Fig. 15. Thin Fuel-Bed showing conversion of Carbon to Carbon Dioxide without secondary formation of Carbon Monoxide.

If the gases now pass through further thicknesses of fuel the carbon undergoes secondary reaction with carbon dioxide, giving carbon monoxide gas :—

$$CO_2 + C = 2CO - 10{,}190 \text{ B.T.U. per lb.}$$

The amount of carbon dioxide is thus reduced to an equilibrium figure of approximately 5 per cent., while the carbon monoxide percentage reaches approximately 12 per cent. Under these circumstances only about 40 per cent. of the heat energy of the coke is liberated unless some means is adopted for recombustion of the carbon monoxide so formed by a secondary admission of air, according to the equation $2CO + O_2 = 2\ CO_2 + 10{,}190$ B.T.U per lb.

Effect of Various Sizes of Fuel.—The correct thickness of fuel with which the maximum percentage of carbon dioxide is obtainable depends on the size of fuel, as a smaller, densely packed fuel would present a much greater surface to the air than would the larger sizes. The optimum thickness for a 2 in. by 3 in. sized coke would be approximately 7 in.; for nut-sized coke 4 in.; and for large coke 10 in. (Large coke is not advised for the boiler as there is a possible risk of hanging up in the hopper.) The effect of this on the actual boiler plant can be seen from Fig. 17. A controlled thickness of fuel-bed, so adjusted that carbon dioxide is formed and no carbon monoxide, is seen in the hopper-fed boiler, where the water legs in the shell of the boiler control the fuel-bed thickness accurately, the thickness remaining constant independently of the quantity of fuel stored in the hopper. In practice a small leakage of excess air inevitably occurs so that a typical gas analysis may be taken as :—

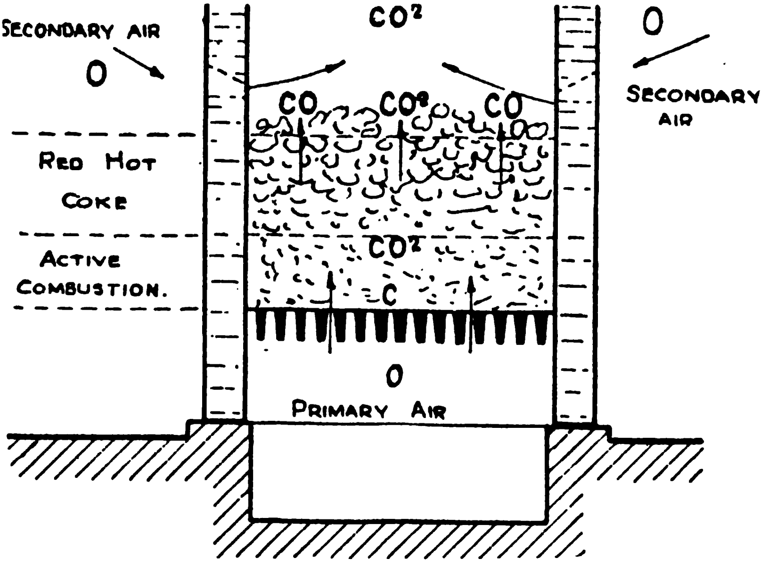


FIG. 16. THICK FUEL-BED SHOWING SECONDARY REDUCTION OF CARBON DIOXIDE TO CARBON MONOXIDE AND HOW ADMISSION OF SECONDARY AIR RECONVERTS CARBON MONOXIDE TO CARBON DIOXIDE.

CO_2	15.5 per cent.
O_2	4.0 „
CO	0.4 „
N_2	80.1 „

The reactivity of the coke, the temperature of the fuel-bed, and the rate of combustion or the rate of supply of air do not appreciably affect the thickness of the fuel-bed at which the complete transformation of oxygen to carbon dioxide is effected. This is because the reaction $C + O_2 = CO_2$ is not governed by the rate at which the molecules of carbon dioxide are formed, but by the rate at which oxygen will diffuse through the stationary film of carbon dioxide, surrounding each carbon particle. This stationary gas film is

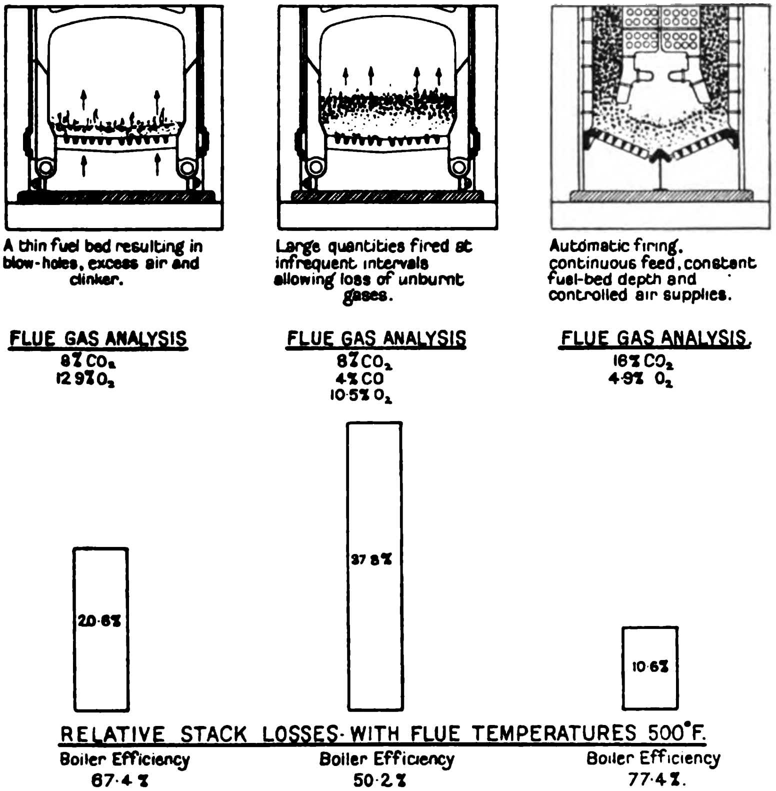


FIG. 17. SHOWING FLUE GAS LOSSES FOR VARYING FUEL-BED THICKNESSES WITH INADEQUATE REGULATION OF SECONDARY AIR SUPPLY.

independent of the reactivity of the coke and of the temperature of the fuel-bed (both factors which appear at first sight to affect the the rate of formation of carbon dioxide to an appreciable extent.)

The Effect of Rate of Combustion on Fuel-Bed Depth.

The air velocity, in other words the rate of combustion on the grate, does affect the rate of diffusion through the film because the thickness of the film itself is almost exactly inversely proportional to the velocity of the air, that is to the rate of combustion—e.g., if the velocity is doubled the amount of oxygen diffusing through the film surrounding the carbon particles in a given time is also nearly doubled, and the amount of carbon dioxide formed is again doubled, thus the height of fuel-bed at which the atmospheric oxygen is completely transformed to carbon dioxide remains constant.

Ash Removal.

The provision of ample grate area goes very far towards eliminating clinker formation, which would be a serious handicap to the operation of any boiler required to run for long periods without attention. The large grate area ensures a low rate of combustion, and a correspondingly low fuel-bed temperature, which is thus maintained below the fusion point of ash, at which the clinker forms.

De-ashing of the boiler is partially automatic, owing to the flow of fuel down the grate gradually working the ash through the bars into the ashpit, whence it may be removed. Ashpit sprays are provided to dampen the ash and thus avoid the possibility of dust. Any clinker formed may be taken out by the fire inspection door, a simple operation which takes only a short time.

The amount of fuel normally consumed by a boiler of one million B.T.U. size on an average day's working is approximately 10 cwt., and the corresponding amount of ash for disposal 1 cwt.

When it is realised that a one million B.T.U. boiler will heat a relatively large building, it will be appreciated that there has been a good deal of exaggeration as to the amount of ash removal necessary from buildings.

Boiler Specification.

An abridged specification of the boiler is appended.

Pressure.—The boiler is suitable for a pressure of 50 lb. per sq. in. or 100 ft. head.

Insurance.—The design and construction is in accordance with the requirements of specialised boiler insurance companies.

Fuel Magazine.—The boiler is provided with magazines with a capacity which will allow the boiler to operate for a period of 18 hours at maximum rating on 2 in. to 3 in. coke fuel of 25 lb. per cu. ft. volume.

Four fuel doors are provided to the magazines. These doors are of cast iron, truly faced to the magazine, and the corners of the edge guides to the doors are undercut so as to prevent the door riding up on the radius in the corner.

Door stops are designed so that there is no possibility of coke getting trapped between the door and stops, thus preventing door closing.

Grate.—The grate may have fixed, mechanically operated, or water-cooled firebars, and it may be divided underneath so that half of the boiler only can be used if required.

Grate Area.—The grate area is based on the following proportions. One square foot of grate area is allowed for every 43,750 B.T.U. per hour output as follows :

500,000 B.T.U. per hour = 11.4 sq. ft.
600,000 „ „ = 13.7 „
750,000 „ „ = 17.1 „
1,000,000 „ „ = 22.8 „
1,250,000 „ „ = 28.6 „

with water-cooled grates a smaller grate area can be used.

Fittings.—The boiler is complete with safety valve and is also fitted with adequate cleaning plugs so that the boiler may be efficiently cleaned when necessary.

Finish.—The finish is of sheet steel with vitreous enamelled olive green or cream front, or of polished sheet aluminium, and relieved by chromium plated corner angles, etc. Machine fittings are chromium plated.

Insulation.—A good insulating brick lining is fitted to the smoke-box doors. All other parts which are exposed to direct heat of the fire or flue gases are efficiently protected with a good insulating brick, except those parts which are water cooled. The whole of the sides and back of the boiler is efficiently insulated with a first-class insulating medium. The space between the steel cover-plates and the boiler shell is packed with 85 per cent. magnesia boiler covering, " Alfol " or glass-silk mattress.

General.—The total height of the boiler and magazine is kept down to the minimum in order to facilitate its installation in existing boiler-houses.

The boiler as supplied by various manufacturers varies in the smaller details, and to a certain extent in overall size, and the boiler is now provided in cast iron as well as mild steel construction. While the gravity-fed boiler has a great appeal for installations where ample headroom is available, the existing types of hand-fired boiler are still the main standby of the heating trade, and modifications to the design to improve the efficiency, such as the provision of carbon monoxide prevention doors have taken place from time to time.

The Hand-Fired Boiler.

Carbon Monoxide Prevention Doors.

While the hand-fired boiler has not undergone any radical change over a large number of years, one recent improvement has made for a definite increase in efficiency, that is, by the provision of carbon monoxide prevention doors. The doors are arranged with slits actually beneath the level of the fuel-bed, of such a design that secondary air is always heated before mixing with the carbon monoxide, so that combustion takes place readily. The arrangement, however, is particularly successful in giving very nearly the correct proportion of secondary air to consume the carbon monoxide formed over a complete intercharging period. Fig. 18 shows how the proportion of secondary to primary air is reduced as a hand-fired boiler fuel-bed decreases each hour after being fully charged. As the fuel-bed decreases the amount of carbon monoxide present becomes less and the proportion of secondary air required also decreases. At the same time the resistance of the fuel-bed to the passage of primary air also decreases, and it is found that more primary air can be drawn up through the fuel-bed and into the combustion chamber, thus reducing the proportion of secondary air obtained through the carbon monoxide prevention doors. This prevents a very large excess of secondary air when the fire has burned low, while giving sufficient to burn off all the carbon monoxide in the initial stages of an inter-firing period.

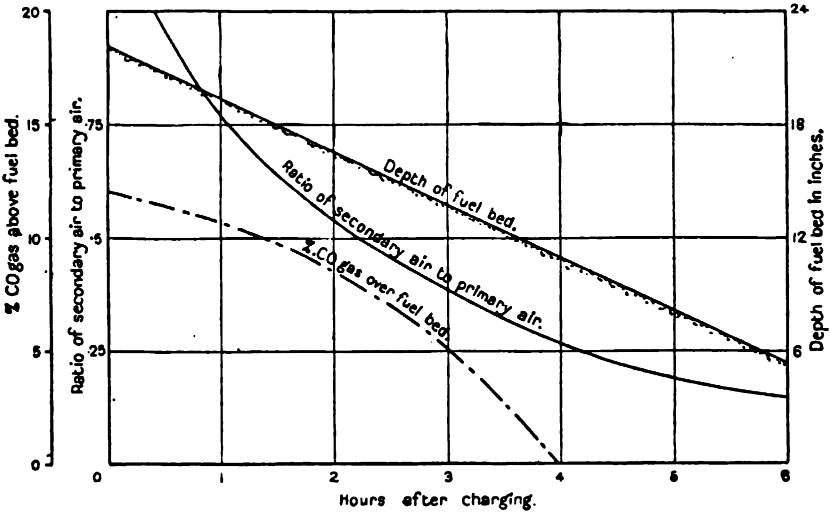


FIG. 18. SHOWING HOW THE PROPORTION OF CARBON MONOXIDE IN THE GASES ISSUING FROM THE FUEL-BED AND THE RELATIVE PROPORTION OF SECONDARY TO PRIMARY AIR VARY DURING THE COMBUSTION STAGES OF A HAND-FIRED HEATING BOILER BETWEEN TWO CHARGING PERIODS.

An actual test carried out by the boiler-makers shows that a reduction of the carbon monoxide content of the flue gases of from

2.5 per cent. down to 0.5 per cent. may be made, giving a fuel saving of as much as 10 per cent. The actual carbon dioxide readings are shown in Fig. 19.

The Operation of Small Boilers to Prevent Failure at Night.

One of the most widely used solid fuels used in small domestic boilers—coke—has an ignition temperature of approximately 800° F. It is found that there is a tendency for boilers, particularly very small ones, to lose temperature under low load conditions until the fuel-bed temperature falls below the ignition temperature, and the fire finally goes out. This may be avoided by maintaining a warm chimney so that a flue pull is always available whenever there is a call for heat. If a check-damper is fitted to the side of the boiler so that the air is admitted into the flue, the air passes over the hot fuel-bed as shown in Fig. 20 and is thus warmed. The chimney maintains a sufficiently high temperature to ensure a continuous chimney draught, and this ensures the boiler picking up when a

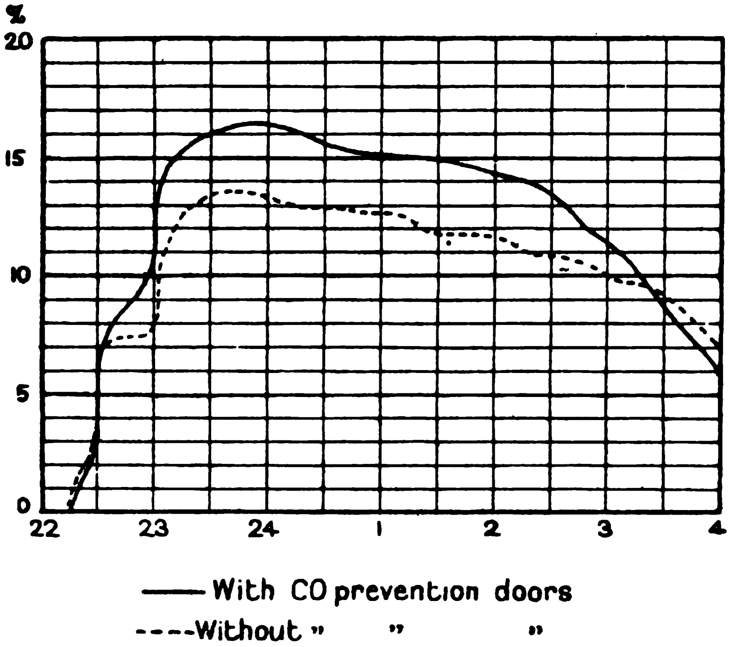


Fig. 19. Carbon Dioxide percentages for a Hand-Fired Heating Boiler during a 6-hour intercharging period with and without Carbon Monoxide Prevention Doors. (Courtesy of National Radiator Company, Hull.)

call is demanded by opening the dampers whether automatically or by hand, and obviates the difficulty so often found of these boilers going out overnight when the draw-off is at a minimum.

MECHANICAL STOKERS.

Unit stokers for fitment to the existing types of central-heating and steam-raising boilers are now well established. They handle a wide range of fuels, and are suitable for completely automatic control.

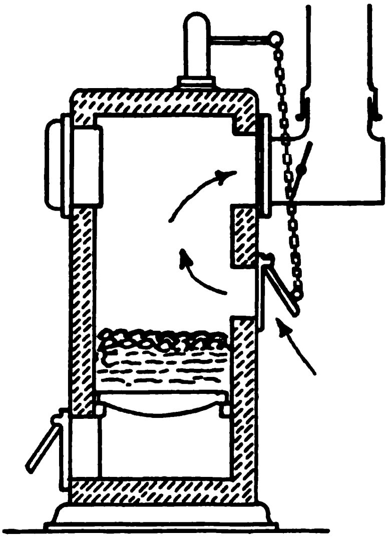


FIG. 20. SHOWING THE MODIFICATION TO A THERMOSTATICALLY CONTROLLED DOMESTIC HOT-WATER BOILER TO PREHEAT THE CHECK-DRAUGHT AIR AND MAINTAIN A WARM FLUE UNDER LOW LOAD CONDITIONS.

The various types are :—

1. Producer-type stokers.
2. Underfeed stokers.
3. Moving-fuel stokers.
4. Overfeed stokers.

Producer-Type Stokers.

The best-known stoker has a sloping chain-feed mechanism, conveying the fuel from the main hopper to the reaction zone. The air going through the thick fuel-bed generates carbon monoxide, which is burnt by the further admission of secondary air in the boiler itself. This stoker is normally fitted to existing central-heating boilers. The air is supplied by a forced-draught fan, the fuel by a moving grate, controlled by a variable-speed motor, the whole being controlled by a thermostat. The producer itself is surrounded by a jacket, from which steam is generated and passed under the bars, to assist in the formation of carbon monoxide. Any excess steam passes through a heat exchanger to warm the main water flow from the boiler.

The stoker is suitable for all grades of coke and small grades of hard coal, and is a useful method of providing automatic feed for an existing boiler installation.

Underfeed Stokers.

In the underfeed stoker the fuel is introduced from a hopper to the fire-pot by a worm or screw enclosed in a tube as shown in Fig. 21. The range of sizes cover from 140,000 B.T.U. to 6,000,000 or even 9,000,000 B.T.U. The common practice is to employ the circular fire-pot on the smaller sizes and the rectangular fire-pot on the larger models. The method of introducing the air into the fire varies in detail considerably, but generally the air is introduced through a series of tuyere blocks some distance below the top of the fire-pot. In most cases these tuyere blocks are renewable. Some makers introduce an additional supply of air on the outer side of the fire-pot to burn off any volatile matter escaping the main air supply. As fuel burns it is pushed by the oncoming fuel over the edge of the fire-pot, where it is removed as ash or clinker. In most cases the fire-pot is surrounded by fire-brick or it may be surrounded by a grate, thus allowing the air to be introduced into the ashpit and the boiler to be hand-fired in the event of a breakdown.

Where a totally-enclosed hopper is employed, a branch air pipe is taken to the hopper. The circulation of air in the hopper prevents condensation and keeps the fuel dry. Wet fuel is apt to cake and cause undue strain on the mechanism, as well as giving corrosion trouble.

Drives and Gearboxes.—The usual form of drive is a direct coupling to the motor with a " V " belt drive to the gearbox. Occasionally the motor is mounted independently, and the drive from the motor is either by belt or chain. In other makes the fuel feeding worm is driven direct from the gearbox. Some makes of stoker have a constant drive control, the fuel supply being stopped and started according to the demands of the thermostat. Others have two or more, up to as many as 15 speeds. The gearboxes are normally hand-operated and in the form of a ratchet wheel and pawl.

Safety Device.—Safety devices are employed to guard against damage to the machine in the event of iron or any hard substances finding their way into the fuel. These are usually in the form of shear pins or a slipping clutch. Most makes have an automatic

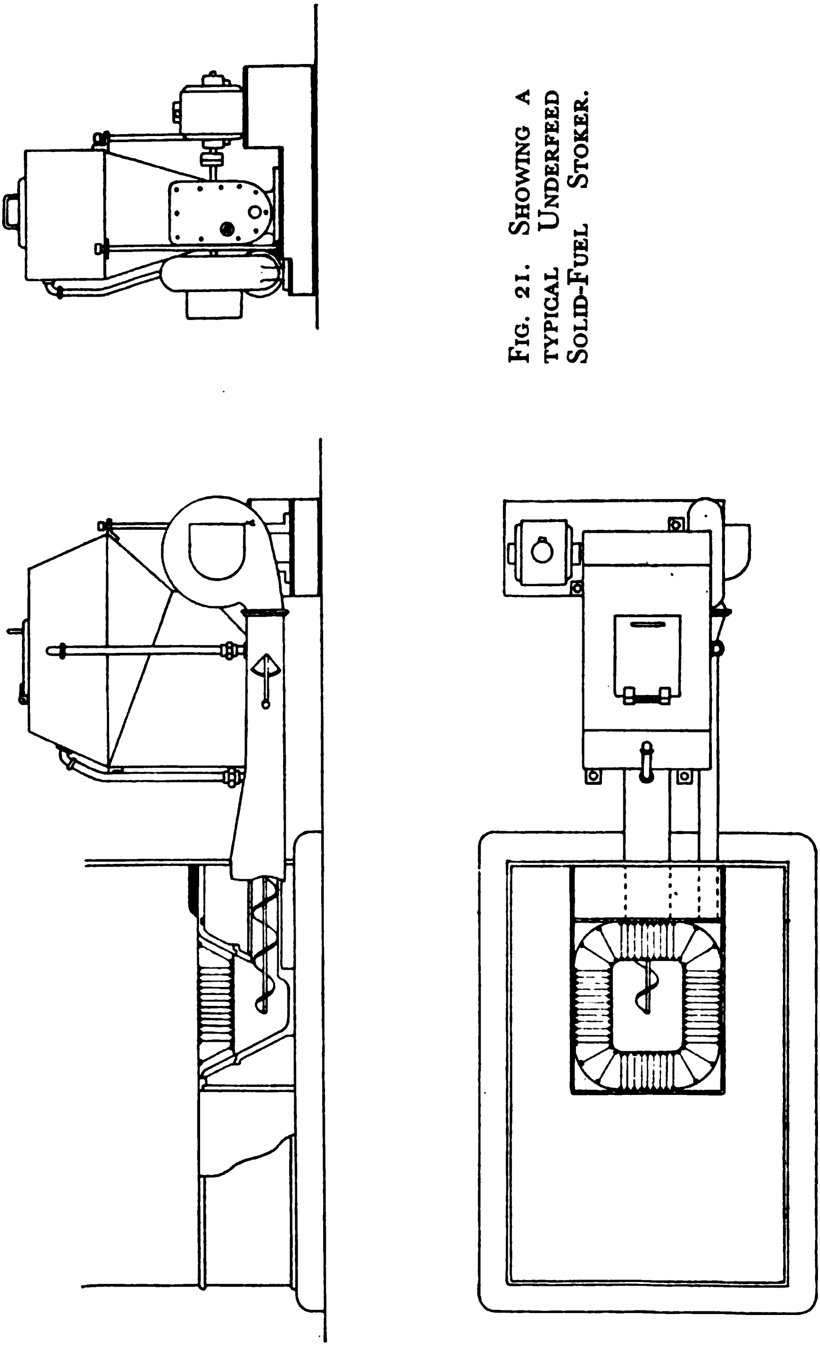


FIG. 21. SHOWING A TYPICAL UNDERFEED SOLID-FUEL STOKER.

contact breaker, fitted in the electric starting and control gear, for breaking the current should the motor tend to overload.

The control of the air on the forced-draught fan is usually by hand adjustment, but on some makes adjustment of supply is by a thermostat,

Automatic Control.—Four types of automatic control are fitted :—

(*a*) By room thermostat.
(*b*) By water limit thermostat.
(*c*) By flue-stat.
(*d*) By a time switch.

Water thermostats are exactly as described previously for coke-fired boilers. The flue-stat is merely installed to come into operation periodically to prevent the fire going completely out when the stoker is working under low load. A time switch may replace the flue thermostat for this purpose.

Self-feeding Devices.—A worm can be connected to the main fuel store to feed the stoker. Where a direct feed is not possible a universal joint is employed. This avoids refilling the stoker hopper twice or three times a day. Feed may also be by conveyor into the stoker hopper or by gravity if it is possible to arrange the main fuel hopper in a sufficiently elevated position.

Most of the stokers need ash and clinker removal by hand. One or two are fitted with automatic ash-removal gear, consisting of a worm which collects the ash and delivers it into the ash-removing bin. This is only satisfactory where anthracite is used as fuel and where the fire-pot is surrounded by a grate, so that the ash is allowed to fall away from the fire, the clinker being still removed by hand.

One objection raised to the underfeed form of stoker is in obtaining the correct adjustment of the relative proportions of primary and secondary air. With any variation in the amount of volatile matter in the fuel, or the load under which the stoker is operated, the relative proportions of air and fuel vary, so that it is very difficult to get a close enough range of adjustments to obtain efficient operation under all conditions, and to ensure the maintenance of installation efficiencies after a few months' operation.

Of the non-volatile fuels coke is too abrasive to be used successfully in this type of apparatus.

Costs.—The cost of stokers ranges from £90 for a 200,000 B.T.U. boiler to £300 for a 2,500,000 B.T.U. boiler. Taking an example, the fitting of a stoker to a 1,250,000 B.T.U. boiler.

Cost of stoker	= £200
Cost of installation	= £20
	£220

These figures naturally vary with the make.

The feeder model costs £14 extra.

Automatic ash removal costs approximately £14, making a total cost for the installation of £248.

Electrical Power.—The electrical power required to drive the stoker varies from ¼ h.p. for a 200,000 B.T.U. stoker to 5 h.p. for a 6,500,000 B.T.U. stoker, which is approximately 10 units of electricity per ton of fuel fired.

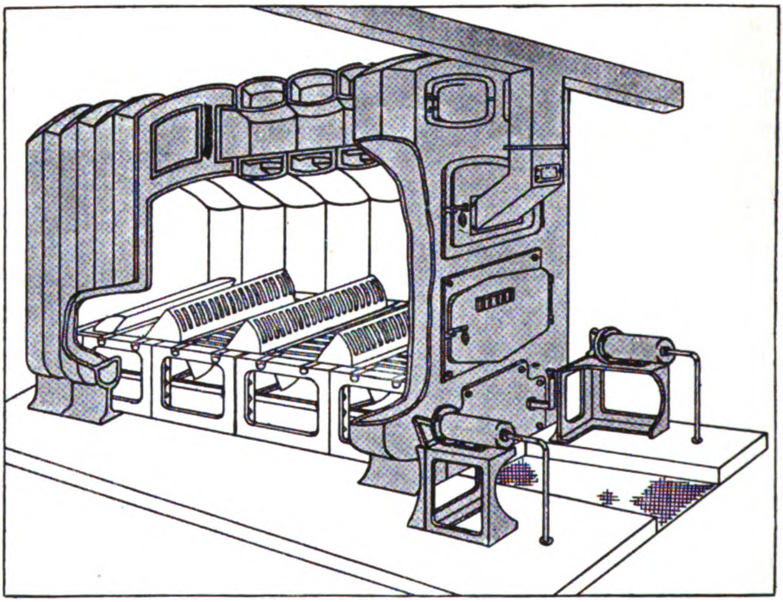


FIG. 22. THE FILMA STOKER, SHOWING ALTERNATE GRATE SEGMENTS RAISED TO PUSH THE FUEL FROM THE FRONT TO THE BACK OF THE FIRE.

Moving-Grate Stokers.

A progessive stoker for solid fuels (Fig. 22) has recently been introduced, consisting of a grate fitted in segments, each segment revolving 90° about horizontal axes arranged in alternate sets, operating at different times, gradually propelling the fuel from the front to the back. Each alternate set is controlled by a hydraulically operated piston, which is regulated by a time clock, so arranged to put its set of grates into operation once in a given period of time, approximately 5 minutes. This period can be altered as occasion demands. The main feed to the boiler, which is to the front of the grates, as well as the grate-operating mechanism is controlled by a thermostat. The air supply is controlled by the same thermostat or by a second thermostat, either of the damper-operating motor or self-acting type.

The thickness of fuel-bed in the fire is adjusted by the timing of the grate-operating mechanism, and once this is set the working of the stoker is completely automatic.

Up to the time of writing this paper tests have not been completed on the equipment, but there is every hope of its reaching a commercial stage during this heating season.

Chain-Grate Stokers.—The chain-grate stoker for heating boiler is similar to that used on large power boilers, consisting of an endless chain, on which the fuel is burnt. The whole of the stoker is of unit construction, the lower portion of the chain grate passing through the ashpit. The fuel is fed onto the grate from a hopper, the depth of the fuel-bed being regulated by a vertical slide valve, hand operated. Careful adjustment of the speed is necessary to avoid fuel not completely burnt being pushed over the edge of the stoker with the ashes. It is in point of fact doubtful whether any satisfactory adjustment may be obtained which ensures that this does not happen. Thermostatic control may be applied by a room thermostat or boiler thermostat shutting on and off the chain-grate mechanism as well as the air supply.

Overfeed Stokers.

Thrower or sprinkler type stokers have been applied to central-heating boilers. These have a rotating hammer, throwing the fuel from a hopper in front of the boiler onto the grate. Coke, anthracite or bituminous coals can be used, although the abrasion with coke necessitates a hard steel thrower mechanism. The adjustment of the stoker to the correct fuel-bed depth, and the adjustment of the speed in conjunction with the air supply are so far not altogether satisfactory, and as a result these stokers have not been introduced to this country to any appreciable extent.

GAS-FIRED BOILER PLANT.

The use of gas for central heating has shown development in several directions, and is due in part to the special central-heating tariffs recently introduced by many gas undertakings throughout the country. Gas-fired units for use with hot-water central-heating systems and hot-water supply have been developed in more compact sectional designs and more attractive finishes.

Considering thermal efficiency, it must be borne in mind that gas water-heating units have had a high efficiency for many years, and there has been little room for improvement in this direction. Advances, however, have been made by developing units using luminous burners which are capable of being turned down to a very low gas rate under thermostatic control. A high degree of lagging on the distributing pipes can therefore be used and a highly efficient system obtained, which puts gas on a more economic basis with the cheaper if cruder fuels.

The substitution of gas for other fuels by means of simple conversion sets, whether of the luminous-flame type or aerated type in conjunction with refractory materials, shows progress following American practice.

Trials have also been made of designs based on the gross calorific value of the gas in which condensation of part or all the water formed on combustion of the gas takes place. The trouble formerly experienced with corrosion of the flues due to a condensate has been overcome by the choice of specially designed materials which are impervious to the action of the condensate. The low flue-gas temperature necessitates some form of draught assistance, and an induced-draught fan has been most effectively employed, the air inlet being so arranged that it induces its own proportion of gas from a low-pressure supply.

Finally, developments in connection with automatic operation, such as thermostatic or clock control, which have been made in connection with solid fuel are easily, and have been, applied to gas.

ALL-IN HEATING CONTRACTS.

Central heating by solid fuels, whether the feed or the control is automatic, still requires a small amount of attention at least once a day, and in certain cases the client may not feel disposed to give even this. It is possible to negotiate an all-in heating contract, by which a service contractor will take over the responsibility of supplying heat to a building at a fixed quarterly charge, providing fuel, labour, and attendance, maintenance, and every other service. To do this an accurate estimate of the fuel consumptions of buildings of various types must be made, and this has formed the subject of special studies of the heat losses of buildings during a heating season. The heating contracts might apply equally well to gas- or coke-fired boiler plants.

There is very little doubt that so much fuel is used wastefully through lack of proper supervision of building staff, that there is much scope for this type of service, ensuring as it would the efficient and adequate use of fuel in the central-heating field.

A chronicle of improvements in such a wide field must of necessity be disjointed, but it is felt that sufficient information is given to indicate the heating trade's striking record in recent years. The enthusiastic reception given to some of the later developments by the general public indicates an even greater expansion in the use of the various systems of artificial heating.

In conclusion the author makes grateful acknowledgment to the directors of the Gas Light & Coke Company, for permission to publish this paper, and to the various firms who have so kindly supplied information and illustrations. The successful outcome of the development work which the author is privileged to describe is largely due to the work of the Chief Engineer, the Chief Chemist, and other members of the staff of the Gas Light & Coke Company. Special thanks are due to Mr. C. A. Masterman, and to the Technical Section of the Coke Department for assistance in the preparation of the paper.

DISCUSSION.

Mr. E. R. Dolby said he had been greatly interested in the paper. He had not had an opportunity of seeing it until he arrived that evening, however, and he proposed to confine his remarks entirely to the gravity-fed coke boiler. By the courtesy of the author, he had had the privilege of visiting the Fulham gas-works, where he saw one of these boilers which had been imported from the United States, and he understood it was the first boiler of the type to be used in this country. Since that time he had seen other English-built boilers, one at the building of the Architectural Association and two larger ones at the Imperial College of Science.

As a consulting engineer he was greatly interested in this, to him, novel type of boiler, but he saw in a moment that it might be somewhat difficult of application. His firm was responsible for quite a number of new schools. Each of these had a boiler-house in the basement, and above the boiler-house were some important rooms belonging to the school, so that it was quite impossible to make trap-doors in the floor over the boiler-house, and therefore he could not see how it would be possible to use the particular type of boiler in question in those schools. It was suggested to him that a chute might be arranged to deliver the coke onto a conveyor in the boiler-house, which might deliver the coke into the hoppers of the boilers ; but first of all the boiler-house was not high enough and secondly the cost would have been prohibitive.

He had succeeded in persuading the architects with whom his firm were collaborating to allow him to design a boiler-house to serve two new schools. That boiler-house would have its floor eight feet below ground level, and there would be a fuel floor four feet above ground level, so that the coke lorry could back up against the platform and sacks of coke be pulled straight off onto the floor, where there would be the usual slides. That floor would be roofed in to form a coke-store, so that the coke would be kept perfectly dry and could be stored in sacks or otherwise. He believed that this would prove a satisfactory arrangement for those two schools, but of course so far as he was concerned it was somewhat experimental.

Turning to the question of fuel, he said that for a good many years past it had been the fashion to decry solid fuel and to advertise liquid fuel ; and the first few schools of the group of which he was speaking were each provided with two boilers, one being fitted for oil-firing and the other for hand coke-firing. The present-day slogan, as was well known, was " Burn solid fuel," and the Government was assisting that by a tax of £1 a ton on oil. In the more recent schools, therefore, they had applied a mechanical stoker to each of the two boilers, and were using slack—Scotch washed peas at present—which they could buy delivered at the rate of 22s. 6d. a ton.

It was no use trying to push a new type of boiler before a Council unless one was prepared to say that the maintenance and fuel costs of that boiler would not exceed the previous figure ; and that was where the difficulty came in. The calorific value of the slack which they were using was about 13,000 B.T.U. He had been surprised to learn that Dr. Taylor's company was prepared to guarantee 12,500 B.T.U. for the broken coke which they were prepared to supply, but he assumed that the cost of that coke was somewhere about 34s. a ton. So far as he could see, it was very problematical whether coke at that price could be burned in these new boilers and the cost of heating per million B.T.U., or whatever measure was adopted, kept below, or equivalent, to what it had been before, either with oil or slack. That was the problem. It was necessary to heat these schools at the lowest possible cost, and he would be greatly interested if some of the members present would take up that point.

Mr. W. E. Fretwell said he had been very interested in the paper, although, like Mr. Dolby, he had not had an opportunity of reading it beforehand. Mr. Dolby had shown how it was possible ingeniously to adapt the gravity-fed boiler for boiler-houses where one had not sufficient depth. The main object of the paper, however, was, he thought, to show how coke could be employed for central-heating installations. Personally, he believed—and he thought there would be general agreement on this—that so long as we had in this country a national commodity in the form of solid fuel we should endeavour to burn it.

Unless stokers were more or less in constant attendance, he preferred either hand-fired or gravity-fed boilers to mechanical appliances. If gravity-fed boilers proved to be a success—and the one which he and other members had seen at South Kensington promised to be—it would be a step in the direction of the more frequent use of this type of boiler which, combined with thermostatic control, was what was desired.

He was not sure that one was on altogether safe ground in speaking of cheap fuels. He had endeavoured to get a large quantity of slack coal in a district not more than thirty miles from London, and had been told that the mines were booked up for the next twelve months. He wanted something like twenty tons a week. The difficulty had been overcome by going to another source of supply ; but whether it would be possible to obtain cheap fuel at 15s. or 16s. a ton or less depended on the demand and on the distance from the station to the site. In a report which he made recently he suggested that endeavours should be made to burn coke from the local gas-works, and that was being done.

The relative costs of heating buildings with different fuels was a vexed question, and he did not propose to make any lengthy reference to it ; but there was one thing which, taking his courage in both hands, he would like to mention. In one instance it so happened that there were two schools next door to each other, of identical design, and used for similar purpose, one heated by oil with a low-pressure hot-water boiler and the other electrically. The cost of the oil fuel and electric energy over a number of years was known. It was possible that the electrical installation might be replaced by a hot-water coke-fired boiler installation, and if so a direct comparison could be made for coke, electricity and oil, where the labour costs were the same for each. It was figures of that kind which were wanted.

In spite of all the different fuels, it was interesting to note that the authority which probably had the greatest number of central-heating boilers under its control was the London County Council, and the London County Council in their schools burned, he believed, mainly coke.

It was interesting to notice the cost of automatic stokers given in the paper, was for a 2,500,000 B.T.U. boiler in the region of £300. which approximated to the cost of cast-iron boilers of the same hourly B.T.U. rating. He knew, of course, that it was a question of quantities. It seemed to him that the cost of an oil burner and a mechanical stoker of similar capacity was just about the same.

The fuel servicing of heating systems which the Gas Light & Coke Company were putting forward was very interesting. How the heating trade, caretakers and municipal authorities and other services would take to it he did not know ; but, given a fair trial, he felt certain that it would tend to reduce the cost of fuel considerably. It was the fuel supplier's duty to provide heat at the lowest possible price ; let him provide it and stoke the boiler and give the service required, and then if he could show a saving, and that was done in the case of a number of buildings, the service would advertise itself.

In conclusion, he would like again to thank the author for his excellent paper.

Mr. Alcwyn A. Jones thanked the author for his paper, which brought before the members the recent developments in boilers and their control. There were a few points in the paper which might be criticised, and the first was the author's statement that "One disadvantage of forced-draught equipment fitted to sectional boilers is that air-leaks occur between sections, so that a certain quantity of air is drawn in by natural draught even when the fan is shut down. This, of course, leads to a continued combustion of fuel," and so on. There should be no leakage between the sections if properly installed and if the boiler were efficiently lagged.

With regard to the gravity-fed coke boiler, he would like to ask how often it was necessary to fill the storage hopper during the heating season. According to the author, at the Imperial College of Science the coke storage held about four-days' supply. From that it appeared that for a heating season of 26 weeks there was the nuisance of 45 deliveries. Floor space for fuel storage could be reduced for any type of boiler if the number of deliveries was not considered. In most buildings the boiler-house was not situated so that the coal-plates could be fixed in the pavement for supplying the fuel into the storage hopper over the boilers. The great objection to this type of boiler, as Mr. Dolby had remarked, was the height required for the boiler and its magazine; and, if the method shown in Fig. 13 of the paper was adopted, an increased height of 3 ft. was required beyond the ordinary height of the boiler-room, which made the position even worse. To architects the height of the boiler-room was a point of great importance; they liked to make it as low as they possibly could.

The author talked of de-ashing, but that did not mean that the labour for clinkering was eliminated. How often it was required was not stated, but it was mentioned that *some* hours elapsed before the formation of clinker had a considerable effect upon the output of the boiler.

He noticed that firebars were indicated, and these would certainly require renewal and consequently involve maintenance costs. From that point of view, it would be an improvement in the type of boiler in question if firebars could be eliminated, as had been done in another make, or waterway bars provided.

The flue temperature was given as 500° F., which was high. If it could be reduced to about 300° or 350° a better overall efficiency than 74.4 per cent. might be obtained, because otherwise it was little better than an ordinary heating boiler with thermostatic control.

Personally, he did not like the term "flue pull" in connection with natural draught. The water gauge indicated pressure, because the draught was the pressure difference between the two columns of air inside and outside the flue, the heavier column pushing the lighter column upwards and not the lighter column lifting the heavier.

Dr. F. J. Eaton said the author had described a large number of temperature-control devices and boiler plants, and personally he felt that the lot of heating engineers must be a very hard one when they came to advise their clients on the best system of heating for their particular requirements. Each person who was connected with any type of fuel naturally wished to boost his own type. He felt that some sort of critical analysis was necessary and that heating engineers should be given figures which would enable them to assess the value of a particular system.

The particular system with which he had been connected was that of the thermostatically-controlled hopper-fed boiler. One point with regard to that system which had not received sufficient attention was its degree of flexibility. In the past, the solid fuels had rather gone into disrepute because they were not flexible. Liquid and gaseous fuels can be thermostatically controlled so that when heat was not required the heat supply could be shut-off completely. That was not the case with solid-fuel boilers, of either the underfeed or the hopper-fed type. With the former fuel was continuously supplied to a small fire-pot. It might, of course, be reduced to half speed by a thermostat, but that was about the limit of its flexibility. Air was always being supplied to it, and therefore a certain amount of fuel was wasted. With the hopper-fed type of boiler one had a very large fire, but the design of the boiler was such that the combustion rate could be controlled with the minimum wastage of fuel.

With the hopper-fed boiler there were three points which had to be borne in mind. The first was that, as the author had pointed out, there was a continuous supply of fuel to the boiler, and therefore the fuel-depth was kept constant. The second point was that there was thermostatic control, and the third was that special attention had been directed to the design of the dampers. Those three points, added together, gave one rather more than might have been expected. For example, one normally had a pull of something like 0.15 to 0.20 in. w.g. when the primary dampers were open and heat was required. When the heat supply was not required, the pull was of the order of 0.02 in. w.g. That very small pull, together with the tightly fitting primary-air dampers helped to reduce the heat supply to a remarkable extent. In a series of tests which he carried out recently on a 350,000 B.T.U. boiler, the primary dampers were shut and the heat output was taken at different periods. In five minutes the heat output had dropped from 350,000 to 285,000, in 10 minutes to 259,000, and in 30 minutes to 158,000.

A further test had been made which perhaps would not occur in practice, but which showed the flexibility of this boiler. It was connected directly to a modulator valve ; there was no calorifier, and the water had to pass directly through this valve. The valve was so adjusted that when all the ports were shut, approximately 10 per cent. of the total flow passed through the valve, which meant that a water flow of 40 gallons a minute when the ports were open was reduced to about 4 gallons when they were shut. In that event it might have been anticipated that the temperature of the boiler water would rise very considerably and get out of control, but that was not the case. In the test in question the temperature of the flow water was 169° F. at the beginning of the test. The modulator valve ports were closed and the temperature rose to 208° F. in 20 minutes, and then fell gradually until at the end of 45 minutes it was 184° F.

He thought the answer to Mr. Dolby's question was that the gravity-fed boiler gave flexibility, the combustion was controlled and the result was economy in fuel consumption. With the slack, coal there was a small fire-pot and a continuous supply of air to it and the fuel wastage would generally be greater than in the case of the gravity-fed boiler.

Mr. C. R. Allensby associated himself with previous speakers in thanking the author for his excellent paper. There had been a good deal of talk, he said, about fuels, but heating engineers had to realise that, whatever was said, all the different types of fuels and electricity would continue to be used. We were not going to stop power stations working or get the author out of office by not burning coke, and we were not going to stop the miners working. All the fuels and electricity would continue to be used. The author had shown very well how to burn coke, and from that point of view was to be congratulated on his paper.

Personally, the boiler in which he was most interested was the overhead type as installed at the Imperial College of Science. As had rightly been said, the principal objection to it was the fact that it was too high. It was very difficult to get architects and builders to provide a suitable boiler-house for a boiler of that type. His firm were suggesting putting it in for a block of flats, but he could not see the architects or the builders wanting to spoil a splendid elevation by putting a coke-house in front, which was practically what it amounted to. It was a serious objection to that type of boiler. He was particularly interested in the moving-grate stoker, which the author illustrated, and had had some private correspondence with him about it; but he understood that that particular type was hardly beyond the experimental stage and therefore it was a little early for them to be adopted in practice. It was a type which certainly seemed ideal from the point of view of the heating engineer who had to consider the size of his boiler-house and wished to burn coke.

When he was at the Imperial College of Science and looking at the boilers there, he noticed in the boiler-house a smell of fumes, and he would like to ask the author if there was any possibility of CO working up the coke-feed so as to come out of the hoppers at the top. That would not matter in the case where the hoppers and feeders were fixed outside, because it would escape to the air ; but in a confined space it was something which might lead to serious consequences, and he would be glad to hear what the author had to say about it.

He understood that clinker with the type of boiler in question was avoided by having a very large grate area, a point which would appeal to the manufacturers of coke-fired boilers. With a small grate area and a coke-fired boiler one did get a terrible amount of clinker, which caused general dissatisfaction.

Mr. J. R. Kell, referring to the underfeed type of stoker mentioned in the paper, said he would be glad if, in his reply, the author would say whether he considered that suitable for coke. Personally, he had always assumed that it was not.

With regard to the vexed question of the height of the boiler-house, perhaps the author in his reply would refer to a method which was being developed by his own firm in conjunction with the author, whereby the boiler-house need not be much more than 11 ft. under the beams in height with a feed from the side by means of a travelling skip. He believed that in many cases that would meet the difficulty.

With regard to gas boilers and increasing their efficiency by bringing in the condensation of the steam, he would like to know what happened to the boiler when the condensation was running down the inside, and whether the life of the boiler was impaired thereby.

Mr. W. W. Nobbs said he imagined that one of the principal factors which had induced heating engineers and their clients to use fuels other than solid fuels was the elimination of labour. He thought the boiler-makers were to be congratulated on the development of the gravity-fed apparatus which had been described, and he would congratulate the Gas Light & Coke Company on developing the " all-in " service to which the author referred in the last section of his paper. Personally, that had certainly appealed to him, and he believed he had been one of the first to make use of that development in this country.

The question of getting sufficient height in the boiler-house had to be considered, but obviously where the boiler-room was underneath rooms which were of some value, and where the ground-floor room could not be given up for coke bunkerage, the answer was to go down with the boiler-house. Another method of reducing the height of the boiler-house to accommodate such a plant was to cut down the interval between periods of refuelling. The ideal had been mentioned that evening of a 24-hour run without opening the hoppers to recharge the boilers, but in the case of the majority of buildings to which such plant would be applicable there was necessarily a housekeeper employed, or some man about the house, and in the case of large blocks of flats there were attendants, and possibly even an engineer-in-charge. If one cut down the size of the magazine, by shortening the height of the boiler, more attention would have to be given to it—perhaps three times a day instead of once—but one would do away to some extent with the necessity for greater height.

He had not yet had an opportunity of reading the paper—though, like other members, he would read it and study it later with the greatest interest—but one point which occurred to him while the author was speaking was the necessity for inspection of automatic controls, and he wondered whether such inspection meant a visit once a week, or once a month or what the period was.

The author mentioned the in-leakage of air through sectional boilers. That was very important, and he would like to know whether it referred simply to the boiler as first erected or whether it still applied to an important extent when, for example, the boiler was covered with composition and so on.

Mr. T. G. Noble regretted that the title of the paper was not " heating plant " rather than " boiler plant," because there were some interesting developments on the gas side which the author had not had time to deal with very fully, but which personally he would have liked to hear discussed. He referred particularly to new plant for the local application of gas in low-temperature and high-temperature panels and other units. He proposed to confine his remarks, however, to the actual subject of the paper.

So far as gas " boilers " were concerned, the developments had not been very startling during the last few years, for the very good reason that the nearer one was to perfection the more difficult it was to attain it ! He said that quite seriously, because with gas boilers one was getting somewhere near the theoretical limits so far as efficiency was concerned. There had, however, been a number of developments, with which the members were probably familiar, in the direction of producing appreciably more compact and better looking appliances, and of course sometimes, though not always, appearance was a matter of some importance.

The most significant development so far as gas was concerned, however, was that at least three of the biggest firms of gas-boiler manufacturers in this country had found it necessary to produce a much greater range of boilers, and particularly boilers of larger size. He thought that was significant, because it meant that somewhere or other there must be a demand for these larger gas boilers, and therefore one was bound to assume— although sometimes at meetings of the Institution it was hard to believe it !—that there were a few people who used gas for central heating, despite the fact that it was alleged to be necessarily an expensive fuel.

The developments in central heating by gas were in fact very real, as, in particular, members in the provinces would realise; but there had also been appreciable progress in the London area.

There were one or two questions which he would like to put to the author. In the first place he would like to know whether Dr. Taylor had met with any trouble owing to very occasional failures of current supply. He realised that that did not put the boiler plant entirely out of action, but it seemed to him that it might possibly lead to serious trouble, for example on the hot-water supply side, where the maintenance of high temperature might be very important, for instance, in a hotel.

The second point was possibly a rather theoretical one. Since these boilers seemed to depend very much, and ultimately entirely, on natural draught, he would like to know to what extent the accuracy of control or the general working of the plant was affected by variations in the external air conditions, and more particularly by the aspirating effects of wind over the tops of chimneys. There was no doubt that such winds could cause very appreciable variations in the amount of air flowing up any given flue; and as that, with a given damper setting, might be imagined to affect the efficiency, he would like to know if the author had any information on that point and as to its effect on the accuracy of the thermostatic control from a room thermostat.

In passing, the question of "flue pull" had been raised. He was not very much concerned at the moment with the use of the term, but it was still not entirely generally recognised that the values which the author and other speakers had mentioned really bore no relationship whatever to the draught in chimneys as commonly understood. The figures given as measured by the gauge were a function of the resistance mainly of the fuel-bed or of other air entries at the base of the chimney. If there was a high resistance there one had a big suction recorded, but that bore no relationship to the real draught in the chimney. That point had been elaborated more particularly by Monsieur Véron,[1] and in a less satisfactory fashion by himself in a paper[2] presented to the Institution some time ago.

Finally, he would like to ask if Mr. Fretwell was prepared to exchange results with him. He would shortly be in a position to let him have some comparative figures on gas and coke not on similar buildings but in the same building. If Mr. Fretwell would care to exchange data he would be happy to do so, and possibly at a later date acquaint the members generally with the results.

The President said the Institution always welcomed comments from any visitors who were present at its meetings, and he would be happy to hear any remarks which visitors might wish to make on the paper under discussion.

---

[1] "Nouvelle Theorie du Tirage Naturel." Société des Ingénieurs Civile, October 10th, 1930.

[2] *Domestic Engineering*, June, 1932, vol. 52, No. 6, p. 108.

Mr. W. L. Howe (visitor), supporting what Mr. Noble had said, mentioned that the gas department in Nottingham had now sixty gas-fired installations of various sizes under their control. By " their control " he meant that they maintained the appliances in good condition. Mr. Noble had mentioned that bigger strides had been taken in the provinces than elsewhere in the direction of competition between gas and other fuels. In the case of the schools in Nottingham it had been found that gas could compete with solid fuel. In one particular school a coke-fired boiler was taken out and a gas-fired boiler installed, and the running costs for the two seasons were identical to within a few shillings. The cost for gas for central-heating purposes in Nottingham was 1s. 6d. per thousand cubic feet, and the cost for coke 27s. a ton. Those comparative figures might be of some use to Mr. Dolby, who had referred to school-heating costs in his contribution to the discussion.

He had been very interested in the paper, but was surprised that the author devoted so little space to the use of gas for central-heating purposes.

Dr. F. M. H. Taylor, in reply, said he would try to group the various points raised together as far as possible, because several of those who had contributed to the discussion had mentioned the same questions.

A number of speakers dealt with the height of the boiler-house. As many of the members would be aware, already the height of the boiler itself had been reduced some five or six feet over from those in the installation at the Imperial College of Science which many of them had seen. There were few jobs which would not allow either a little extra excavation or possibly some excrescence on the top of the boiler-house to provide the additional height for storage of fuel If one did as Mr. Nobbs suggested, and attended the boiler twice a day—not three times (as Mr. Nobbs mentioned)—instead of once, the boiler need be only five feet in height, and the room above for the guillotine valve some three feet, giving a total height of boiler-house of eight feet, which was practically the same as that now obtaining in the case of most of the hand-fired jobs. However, if it were necessary to have storage somewhere for the fuel one might normally have it above the boiler just as well as at the side without wastage of space.

As had been stated by Mr. Dolby and others, it was not always possible to put the boilers underneath the opening into which the fuel was fed. Dr. Faber and Mr. Kell had very kindly collaborated in a scheme whereby a skip took coke from a hopper where it could be fed quite easily over to the top of the boiler-house. Another scheme which was now being installed in London embodied the use of conveyors. He mentioned these things to show that in addition to the two methods he had illustrated there were quite a number of ways in which the fuelling could be handled. He would go so far as to say that up to the present he had not come across a job in which it would be literally impossible to provide a satisfactory arrangement without going to inordinate cost to do so.

Mr. Fretwell hit the nail on the head when dealing with the comparison between various fuels. Personally, he wanted to avoid any comparison which might appear invidious. Some 9,000,000 tons of coke were sold, mainly for central heating, in England, and 2,000,000 in London. The amount of small coal at present distributed in London was estimated at less than 200,000 tons ; in other words, 10 per cent. of the total amount of solid fuel. A very strict consideration of efficiencies and prices was therefore, he thought, rather out of the question at the present time, because if the demand for small coal rose to say 15 per cent. of the total figure for solid fuel the price was bound to rise until, B.T.U. for B.T.U., after a certain allowance for the reliability of the apparatus and so on, there would not be any real distinction between the cost of heating by those two types of solid fuel. Possibly that was what Mr. Fretwell was really hinting at when he referred to the point, and personally he felt that it provided the key to the difficult problem. Mr. Fretwell mentioned the London County Council ; they were in fact one of the largest consumers of coke in the country and their schools were fuelled with one or two unimportant exceptions, exclusively by coke.

He agreed with Mr. Alcwyn Jones that no properly installed sectional boiler should show air-leaks between sections. Moreover, the sectional boilers supplied by the majority of manufacturers were such that, if reasonably installed, they did not show these leaks. The fact remained, however, that two or three of the first four or five installations which his undertaking had put in did show those leaks very badly, although they were covered with asbestos lagging. In dealing with these installations he thought one had to take things exactly as they were, ignoring ideal circumstances and taking the actual working conditions. The boilers were not always installed as they should be. Although the boiler he had in mind had been installed for only twelve months, over a period of years these leakages—perhaps one might even call them cracks—did develop, and difficulty of satisfactorily fitting forced draught on automatic control arose. It eventually necessitated a change over to a natural-draught control. It should be pointed out that with a forced draught it was not possible to have a chimney damper or any method of stopping natural draught through the boiler, or one would get a blow-back when the forced-draught fan was in operation.

Deliveries of fuel might be considered a disadvantage, and certainly were to some extent, but in most cases those who delivered fuel, whether merchants or gas companies, would fall in with the wishes of the client. If the fuel were delivered twice a week at 7 or 8 o'clock in the morning, when practically no-one was about, it was not difficult to dispose of it and have the place swept up so that the fact that a delivery had taken place would not be noticed.

With regard to times of cleaning, the boiler with the large grate area almost eliminated clinker, though not completely ; there was a trace of clinker. Clinkering was carried out, it would be seen from the 24-hour chart, only once in the 24 hours. The boiler definitely ran without any attention at all for 24 hours ; one did not have to poke the fire, or anything like that. There was a slight tendency for the output to fall off, but, as could be seen from the chart, the boiler could be so arranged that the falling off in output on 24 hours full load, which would correspond to about 36 hours normal operation, was very small indeed.

The firebars in these boilers would of course be renewable, but the rate of combustion was so low that no trace of wear or tear on the firebars had occurred so far, nor did he think it was likely. Waterway bars could be applied to the boilers, and he agreed that the type of boiler with no firebars had something to commend it.

He was very glad that Dr. Eaton had spoken, because Dr. Eaton had been closely associated with all the work described. Dr. Eaton was one of those who had done a great deal of donkey work quietly in the background which people like himself came into the limelight to describe. It was because of that work that the developments described had taken place, and he personally, and no doubt many of the members, owed a debt of gratitude to Dr. Eaton for his share of the work accomplished.

Mr. Allensby referred to the possibility of CO escaping from the top of these boilers. He agreed that that was a real consideration. Mr. Allensby would not have been troubled with CO in the smell to which he referred ; what he detected was due to bad adjustment of the dampers, and in particular the flue damper, and that had been overcome. A very important point was raised, however ; although he did not deal with them specifically in the paper, there were on the market boilers of this type with forced draught under the grate, which directed a pressure right up through the hopper. He had no wish to criticise a boiler with which he had not been associated, but he was sure that there was a grave risk of CO production, and CO was a deadly thing to play about with, as those familiar with large scale producer plant were well aware. He felt that that was something which should receive very careful consideration from the people concerned. Every year with boiler plant there were serious cases of CO poisoning—there was one last year at a

London hotel—and it was something which reflected adversely on the whole heating trade.

Mr. Nobbs asked a question with regard to the inspection of controls. The controls were inspected once a year for central-heating installations and twice a year for hot-water installations, and so far there had been no indication that it was necessary to carry out inspection more frequently, nor did he think it was worth while extending the interval between inspections.

Mr. Noble asked about the failure of current. That had caused no trouble, but it had caused a certain amount of worry, because current failures were events to be reckoned with, and it was not a nice thing to have the current fail on these jobs. That was why some trouble had been taken to develop a current-failure mechanism.

At such a late hour he thought he might be excused if he refrained from entering into the controversy on flue pull.

The President, in proposing a hearty vote of thanks to Dr. Taylor for his interesting paper, said that it contained a mass of important data and details from which the members would be able to gather a great deal of exceedingly useful information when they came to read through the paper later. From papers such as that which Dr. Taylor had presented it was possible to gather a great deal of extremely useful information, and it would be of value if all those who had carried out experimental work of the kind described would place the data thus secured at the disposal of the Institution.

The heating industry was developing very rapidly indeed, and what was new one day was old the next. The last few years had been a period of rapid development. It used to be a reproach to this country that we wasted more fuel than we used, but at the present time, by such means as Dr. Taylor had described, a great deal of that waste was being avoided. There had been a development from the ordinary fireplace to central heating, and then through that to oil-fired boilers, and now to mechanical stokers, and so on. He thought a self-contained boiler unit with mechanical or gravity stoking and automatic-combustion control would be the ultimate development.

The vote of thanks was carried by acclamation, and the proceedings then terminated.

Building Research Station, Garston, Nr. Watford, Herts.

THE WARMING OF WALLS

By A. F. DUFTON, M.A., D.I.C.

1. In a communication to the *Philosophical Magazine* dealing with the influence of the fabric of a wall,[1] it was pointed out that, while it is well known that some rooms are not readily warmed, complete analysis of the warming of a room is not easy. A partial analysis showed, however, and experiment confirmed,[2] that a room with masonry walls is much more readily warmed if lined with wood or other insulation of small thermal capacity.

A knowledge of the quantity of heat necessary to raise the temperature of a building is a matter of some industrial importance, and the value, for example, of the comprehensive paper on "The relative fuel economy of electricity, gas, oil and solid fuel as heating agents," read before the Institution of Electrical Engineers[3] and before the Institution of Heating and Ventilating Engineers[4] by Mr. A. H. Barker, would have been considerably enhanced if he had been able to offer a reasonable estimate of this quantity.

A partial solution of the problem is now put forward which brings out the fact, ignored by Mr. Barker, that the amount of heat required is a function of the rate at which heat is supplied.

---

[1] *Phil. Mag.*, 1927, vol. 4, p. 888.
[2] *Phil. Mag.*, 1931, vol. 9, p. 1233.
[3] *Journ. I.E.E.*, 1931, vol. 72, p. 269.
[4] *Journ. I.H.V.E.*, 1933, vol. 1, p. 344.

2. For simplicity a homogeneous wall (of thickness *d*, conductivity *k* and diffusivity *h*) initially at uniform temperature is considered and heat is supplied to one surface at a constant rate. The rate of heating is pTk/d, p times that necessary to maintain the desired temperature difference T between the faces of the wall, and the temperature of the second face is assumed to be constant.

In time t the temperature in the wall at distance x from the heated surface increases by

$$pT\left\{1-\frac{x}{d}-\frac{8}{\pi^2}\sum_{0}^{\infty}(2n+1)\,e^{-(2n+1)^2\pi^2 ht/4d^2}\cos(2n+1)\pi x/2d\right\}$$

The rise at the surface, the limit of this as x tends to zero, is

$$pT\left\{1-\frac{8}{\pi^2}\sum_{0}^{\infty}(2n+1)\,e^{-(2n+1)^2\pi^2 ht/4d^2}\right\}$$

and attains the value T when

$$\sum_{0}^{\infty}(2n+1)\,e^{-(2n+1)^2\pi^2 ht/4d^2}=(p-1)\,\pi^2/8p$$

approximately[5] (if p is not less than 1.5) after a time $4d^2/5hp^2$.

For a 9-in. brick wall $4d^2/5h$ is 24 hours, and the time is $24/p^2$ hours.

3. During one winter the rooms of an experimental house at the Building Research Station were heated from 5.30 a.m. to 5.30 p.m., and the amount of heat available was adjusted from day to day so that the prescribed temperature was attained as nearly at 9.30 a.m. as possible. This temperature was maintained until 5.30 p.m., when the heat was shut-off.

In conjunction with a previous season's observations the experiment showed that this intermittent daily heating required 75 per cent. of the thermal energy necessary for continuous heating.[6] This means that in the four hours daily preheating the consumption was equivalent to ten hours normal heating, i.e., $p = 2.5$.

For the 9-in. brick walls of the house, we find from the formula $24/p^2$ that, when $p = 2.5$, the time for the walls to warm up is 3 hr. 50 min., which is in excellent agreement with the actual time of 4 hours.

4. It would seem that, although the conditions postulated are somewhat idealised, the result of the analysis may perhaps afford a sufficiently useful estimate for most practical purposes. The formula evolved has at any rate the merit of extreme simplicity.

---

[5] Within 3 per cent. if p is not less than 1.5; within 10 per cent. if p is not less than 1.3.

[6] *Journ. I.H.V.E.*, 1933, vol. 1, p. 209.

ABSTRACTS

Industrial Process Air Conditioning.*

697.96

Product	Process	Temp. Deg. Fahr.	Relative Humidity per cent.
Cotton	Carding	68—73	50
	Combing	68—73	60—65
	Roving	68—73	50—60
	Spinning	68—73	60—65
	Spooling, Twisting	68—73	65
	Warping	68—73	65
	Weaving	68—73	75—80
Wool	Carding	73—77	65—70
	Spinning	73—77	55—60
	Weaving	68—73	50—55
	Storage for Shipping	68—73	55—60
Silk	Dressing	69—77	60—65
	Spinning	69—77	65—70
	Throwing	69—77	65—70
	Weaving	69—77	60—70
Rayon	Filament Mfg.†	—	—
	Winding	70—80	40—50
	Weaving	80—85	55—60
Confectionery	Chocolate Enrobing	64	55
	Hard Candy Making	69	50
	Storage	30—59	50—55
Tobacco	Softening	84	85
	Cigar & Cigarette Making	69—73	55—70
Printing	Lithographing	69	45
	Relief and Offset	77	45
	Folding	77	65
	Binding	69	45
Baking	Dough-Fermentation	80	65
	Proofing	89—95	80—90
	Loaf Cooling	69	65
Electrical Cable	Winding Insulation	104	5
Cellulose Lacquers	Application	75	20
Munitions	Fuse Loading	69	55
Cereals	Seal Packing Prepared Crisp Cereals	73	45.5

---

* Courtesy The Foxboro Company, Foxboro, Mass.

† Varies according to process, fibre and product.

(*Heating, Piping and Air Conditioning,* U.S.A., September 1934.)

HEATING AND VENTILATING INDEX

Insulation. 536.2

Gas for Heating. Thomson King. 3 pp., 2 illus. Dealing with infiltration, insulating materials, saving due to varying thickness : *Domestic Engineering*, U.S.A., August 1934.

Air Conditioning. 697.96

How to Air Condition Retail Shops for Profit. Harold L. Alt. 4 pp., 4 illus. Dealing with composition of air, relative humidity, and example : *Domestic Engineering*, U.S.A., August 1934.

Hot-Water Heating. 697.4

Pipe Sizing. Leslie Rayner. 3½ pp., 5 illus. Dealing with formulæ, resistances and method of pipe sizing : *The Plumber*, September 1934.

Boiler Plant. 621.183.8

Some Unsuspected Causes of Deficient Output in Steam Boiler Plant. Edward Ingham. 1½ pp. Dealing with the effect of deficient draught on boiler output : *The Steam Engineer*, September 1934.

Greenhouses. 716.3

Central Power Stations and Food Production. C. S. Darling. Dealing with hot-house production combined with power supply : *The Steam Engineer*, September 1934.

Boilers. 621.183.82

Automatic Damper Control on Hand-Fired Lancashire Boilers. 3 pp., 9 illus. Dealing with economies effected by fitting automatic damper control : *The Steam Engineer*, September 1934.

Fuel. 621.182

Saving Money in the Boiler House. Sydney N. Duguid. 2½ pp., 1 illus. Dealing with what a fireman should learn, instructions to firemen, combustion and what it is : *The Steam Engineer*, September 1934.

Thermodynamics. 536.7, 621.101

Elementary Steam Thermodynamics. F. J. Matthews. 2 pp., 1 illus. Dealing with the fundamental laws of Boyle and Charles : *The Steam Engineer*, September 1934.

Automatic Stokers. 621.183.6

Modern Unit Stokers for Heating. 11 pp., 31 illus. Discussion of kinds, features, considerations and methods for use in selecting, coal problem, installation, and service : *Heating and Ventilating*, U.S.A., September 1934.

Air Conditioning. 697.96

Maintenance of the Air Conditioning Plant. A. Warren Canney. 4½ pp., 4 illus. Dealing with running and shutting down, refrigerating plant intermittently, preheater by-pass, cooling tower and checking the heating equipment : *Heating, Piping and Air Conditioning*, U.S.A., September 1934.

Wind and Heat Loss. 536.2

Wind Velocities Near a Building and Their Effect on Heat Loss. F. C. Houghten, J. L. Blackshaw and Carl Gutberlet. 6 pp., 7 illus. Describing test and results. : *Heating, Piping and Air Conditioning*, U.S.A., September 1934.

Air Conditioning. 697.96

What is the Cooling Load Factor in Air Conditioning? John Everetts, Jr. 3 pp. Dealing with elements of cooling load factor, heat transmission, sun effect, internal light and power load, people load and outside air load : *Heating, Piping and Air Conditioning*, U.S.A., September 1934.

Insulation. 536.2

Is it Possible to Over-insulate? Siegfried Ruppricht. 2½ pp., 3 illus. Dealing with insulation and the design of refrigerators and the ice box *Refrigerating Engineering*, U.S.A., September 1934.

Welding. 671

Welding Cast Iron. W. Steel. 3 pp. Dealing with processes, preheating, expansion and contraction, welding rods and bronze welding : *The Welding Industry*, September 1934.

Water Softening. 621.194.3

The Control of Water Softening and Boiler Feed Water Conditioning. H. E. Evans and P. Hamer. 6½ pp., 1 illus. Dealing with control tests and analytical control of blowdown and feed water conditioning : *Fuel Economy Review*, Vol. 13, 1934.

Drying. 542.68

Principles and Practice of Drying in Industry. E. Knowles. 10 pp. Dealing with functions of heat and air, stages of drying, natural drying, classification of driers and estimating heat and air requirements : *Trans. of the Institution of Engineers-in-Charge*, August 1934.

INSTITUTION OF HEATING AND VENTILATING ENGINEERS

REPORT

SESSIONAL MEETING, LONDON, NOVEMBER 7th, 1934.

A Sessional Meeting of the Institution was held in the Lecture Theatre of the London School of Hygiene and Tropical Medicine, Gower Street, London, W.C.1, on November 7th, 1934, the President, Mr. R. C. Ching, in the Chair.

There were about sixty present, the following signed the attendance register :—Messrs. J. H. Bryant, L. A. Forni, E. L. Joselin, C. Ovenden, A. B. Potterton, T. H. Hatchett, J. G. Ford, J. L. Waller, J. C. Cobham, G. T. Carter, L. Copeland Watts, W. E. Brown, A. Ord, B. A. Pountney, F. S. Reed, J. C. Byles, R. J. Dickson, C. S. K. Benham, Alcwyn A. Jones, L. A. Baines, R. C. Ching, F. J. Colls, T. E. Chatterton, A. K. Warner, H. Leslie Egerton, J. N. Bottrill, A. Hunt, and T. E. Barnes (London) ; H. E. F. Heath (Ilford) ; N. E. Jackson (Beckenham) ; and visitors : Misses Adria Buchanan and J. Arnott, Messrs. H. C. Cawood, H. Rockwood Stevens, L. C. C. Rayner, S. F. Newcombe, J. Pickup, T. Bedford, C. G. Warner, R. A. Woolidge, T. W. Dowell, S. R. Brown, Freeman Horn, E. Partridge, A. E. Thomas, F. H. Vincey, E. B. Edwards, L. Nettleship, T. Gilchrist, and Lt.-Col. F. P. Barnes, D.S.O. (London) ; F. D. C. Allen (Harrow) ; J. Wainwright (Surbiton) ; and W. F. Still (Newcastle).

The President introduced the reader of the paper, Dr. G. P. Crowden. Dr. Crowden, he said, would feel quite at home when speaking in the Lecture Theatre, as he was Lecturer in Industrial Physiology at the London School of Hygiene and Tropical Medicine.

Dr. G. P. Crowden then read his paper on "Metallic Insulation," illustrated by lantern slides, specimens and demonstrations.

METALLIC INSULATION

By G. P. CROWDEN, M.Sc., M.R.C.S., L.R.C.P. (Lecturer in Industrial Physiology, London School of Hygiene and Tropical Medicine.)

SESSIONAL MEETING, LONDON, NOVEMBER 7th, 1934

FROM the earliest times man has had to face, in nature, changes in the physical environment which have forced him, for self preservation, to make use of the heat insulating properties of materials, whether furs, skins or vegetable fibres for clothing; or wood, stone or earth for dwellings. To his conscious mind, sensations of discomfort, but instinctively self-preservation, provided the urge for making such use of these materials ; and although to-day, in the rapid and extensive development of machines, plant and industrial processes involving the production and economic maintenance of every grade of temperature from that of liquid air to the melting heat of metalliferous ores and the electric furnace, the engineer faces and solves vastly more difficult problems of heat insulation, we find that the study of the use of insulation for increasing human comfort and health is still in its infancy, and that in respect of clothing, housing and transport much remains to be done for the human machine.

The modern custom is to supply external heat to keep our bodies warm in buildings, where we might to a very large extent use insulation to prevent us getting chilled, or, on the other hand, in the face of climatic conditions of tropical heat, we either put up with the limitation of our bodily and mental activities, which the environment enforces, or if we can afford the cost we supply refrigeration and air conditioning to keep us cool in places where, by suitable insulation against external heat, we might easily improve living and working conditions. I realise that the humidity of the air is, in some localities, the physical factor of major significance from the point of view of comfort and health, but the scope of this paper is limited to the consideration of metallic insulation against heat or cold, and therefore I shall confine myself to the past history and the present position of the study, and in particular to the practical application, of this type of insulation to human needs.

It is not possible for me to deal with the subject of metallic insulation from the engineering point of view for I am not an engineer or a mathematician, and therefore I trust that you will bear with me if I appear to treat the subject in rather an elementary way, for I regard it as essential, in the first place, to have the elementary but fundamental principles and problems clearly enunciated.

Historical Notes.

In the year 1804, John Leslie (later Sir John), the eminent Scottish mathematician and physicist, published his classical researches on radiant heat in his book *An Experimental Inquiry into the Nature and Propagation of Heat*[1]. During the last few weeks, in the course of the preparation of this paper, I have consulted Leslie's original publication for the first time, and have found in it a wealth of information on the subject of metallic insulation which is truly amazing, and which is not commonly referred to in text-books.

With his cubical canisters containing boiling water, the familiar Leslie cube which has been part of the regular equipment of the physics laboratory for generations, he showed by means of a reflecting mirror of tin, and his differential thermometer placed at the focus of the mirror, that a lamp-black surface emits eight times as much radiant heat as a bright metallic surface of tin. Taking the reading of the differential thermometer as 100 degrees when the lamp-black surface of his cube was exposed, Leslie found that writing paper emitted heat equivalent to 98, crown glass 90 and polished tin only 12 degrees. He observes—

> " but any side of the canister covered with tinfoil, and brought in due position, will manifest precisely the same action. To produce the peculiar effect, it is only requisite to employ a clean metalline surface."
>
> " Thus in its affection to heat, is tin radically distinguished from blacking, or paper or even glass, since compared with them, it exhibits only about the eighth part of the energy. In both cases the heat of the presented surface must obviously be the same, and yet it is capable of producing at a distance effects so widely different." pp. 18-19.

In other experiments, Leslie covered the focal ball of his differential thermometer with tinfoil, and found that although he exposed the black face of his cube to the reflector, the focal ball at the focus only heated up to 20 degrees. He deduced that the tinfoil reflected the heat and observed—

> " Tin is, therefore, five times less susceptible to the impression of heat than glass, and thus the very remarkable distinction already noticed is conspicuous in the reception of heat, as well as in its propagation." p. 20.

He apparently tried as many other metals as he could obtain, and concluded that metallic surfaces generally possessed these properties, with only slight variations from metal to metal.

In other experiments he interposed sheets of tinfoil, tin sheet, glass or paper in the air space between his cube and the reflector, and found that the metal foil was as effective as sheet metal of much greater thickness. He studied the effect of interposing two bright sheets of tin between the canister and the reflector, and noted the high degree of insulation afforded by employing bright metallic surfaces bounding an air space. In other experiments he used small cubes or cylinders, which he filled with hot water and noted the time of cooling of the vessel alone or when inserted into one or two larger cases with metallic or painted surfaces. His description of one experiment was as follows :—

> " And a square canister of three inches, that cools from 20° to 10° in 117′, took 335′ to perform the same effect, after it was enclosed within two similar cases of four and five inches." p. 381.

In this experiment, the canister itself and the outer cases had bright metallic surfaces and ½ in. air spaces separated each case from the next. He comments on the " property of confined air to retard the progress of cooling " and observes that " by employing a series of concentric cases, or septa, this effect is wonderfully heightened." Moreover, he states that for the sake of clearness he divides his study of this subject into three branches :—

(i) " When the surface of the internal canister and its several cases are metallic.
(ii) When these surfaces are all painted, or consist of glass, and
(iii) When they are composed partially of both sorts." p. 374.

I have quoted these experiments at some length because, as far as I am aware, John Leslie was the first to demonstrate the fundamental facts regarding the physical properties of high reflectivity and low emissivity for radiant heat possessed by bright metallic surfaces, and to show by experiments that very thin metallic foil behaved in this respect like a thick sheet of bright metal, and that by surrounding a hot body by septa with bright metallic surfaces, the insulation by successive layers of air was materially greater than when the air layers were separated by sheets of material with non-metallic surfaces, such as glass or painted screens.

In the early part of last century, the standard books[2] on heating and ventilation contained many references to Leslie's work, but little practical use appears to have been made of his discoveries, possibly because, as Leslie himself pointed out, the oxidation and tarnishing of the bright metallic surface of tin increased its emissivity and decreased its reflecting power for radiant heat.

In 1859, Sir John Tyndall began his researches on radiant heat, and while at the Royal Institution confirmed and elaborated Leslie's work. Tyndall used radiation thermopiles and sensitive galvanometers in his researches on the radiating properties of metals, non-metals and gases, and in his book *Heat as a Mode of Motion*[3] he remarks that " The thinnest metallic film furnishes a powerful defence against the absorption of radiant heat."

In 1884, Thompson and Stanley[4], the former an engineer in the City of London, invented a method of improving the insulation of hot pipes by means of an outer casing of tinned iron or tinfoil paper, fixed so as to ensheath corrugated insulating material of low conductivity which surrounded the pipes. In the same year, Hicks,[5] of Chicago, described a method of reducing the loss of heat from boilers and furnaces by means of screens of metal foil adhered to asbestos sheets, which were placed either upon or adjacent to the hot surface. He described how the reflection of heat back to the hot surface and the small radiation of heat from the outer bright metallic surface combined to lessen the loss of heat and improve working conditions.

In more recent times (1918), evidently stimulated by war-time necessity for keeping food warm, a doctor Round,[6] of Sydenham, invented a food container made up of nested covers with intermediate air spaces, a construction similar in principle to the nested boxes which Leslie used in some of his experiments to which I have already referred. In the description of his food container, Round states that metallic foil may be used for the partitions separating the various layers of air in the hollow walls of his box, but he makes no reference to the fact that by so doing, he would make use of the physical properties of high reflectivity and low emissivity for radiant heat possessed by the surfaces of the foil, and that this would increase the efficiency of the insulation as shown by Leslie.

So much, then, for a summary of the past history of metallic insulation. I must now turn to the present, and at the outset, I feel it my duty to indicate to you how I have been led to study such a subject as heat insulation, which is usually regarded as a matter concerning engineers and physicists.

The Present Study.

About three years ago, I attended a lecture given by Colonel Stammers in the School of Hygiene, to a lay audience of people intending to proceed to the tropics. In the course of his lecture he suggested that by painting the inside of tropical helmets with aluminium paint, greater protection from the heat of the sun would be afforded. As a matter of physiological interest I carried out some experiments to see whether this was the case, and to determine whether the temperature above the wearer's head was measurably lower with the aluminium painted interior than with the usual fabric lining of the helmet. I found that aluminium paint only slightly reduced the temperature to which the head was subjected as compared with the temperature reached when a similar, but unpainted, topee was worn under identical conditions of radiant heat. However, on testing the radiating properties of other materials by means of the Moll radiation thermopile coupled to a sensitive galvanometer (which apparatus I had used for measuring the skin temperature of children's hands in panel-heated classrooms),[7] it appeared well worth-while to try tinfoil and aluminium foil in the helmets in view of their very low-emissivity values as compared with aluminium paint.*

In the air-conditioning room in the basement of the School of Hygiene conditions of tropical heat were reproduced and maintained, while the experimental subjects sat, wearing the topees, under electric bowl radiators (Fig. 1). Thermocouples were fixed above their heads as in Fig. 2, and records of temperature were taken for equal times of exposure to radiant heat.

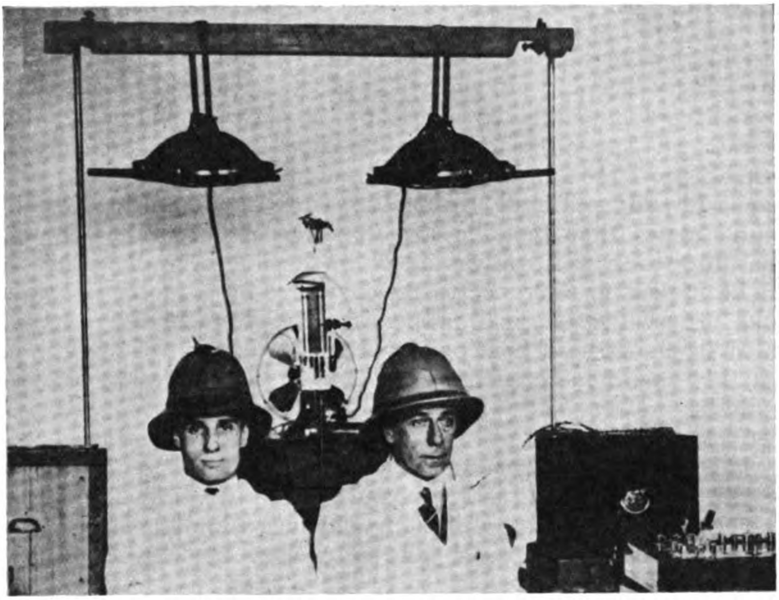


FIG. 1. LABORATORY TEST OF METALLIC INSULATION IN SERVICE TOPEES.

With the metallic-foil linings, sometimes as much as 20° F. lower temperature was registered, and the subjects undoubtedly felt an increase in comfort, for sweating was either absent or much less profuse than with the usual fabric linings. These were purely laboratory experiments, but the results were so definite that the Army Hygiene Authorities afforded me the opportunity of carrying out field tests in the Egyptian desert in August 1932.[8,9] The field tests confirmed the laboratory results, and, as only such tests can show, they indicated what improvements were necessary before the physical properties of the bright metallic surface of the aluminium foil could be made of practical use under working conditions. Thus it was evident that the metallic foil must be firmly adhered by a waterproof adhesive to some light but strong fabric, and that the lining must be fitted to the helmet so as not to interfere with the free ventilation already provided. These matters were then studied in the laboratory and, with the co-operation of the helmet manufacturers, the linings were perfected as far as possible, and topees with these linings have now been in use for some time in many parts of the world.

---

*For tables of emissivities see Fishenden and Saunders "The Calculation of Heat Tranmission," 1932. H.M.S.O., pp. 17-22.

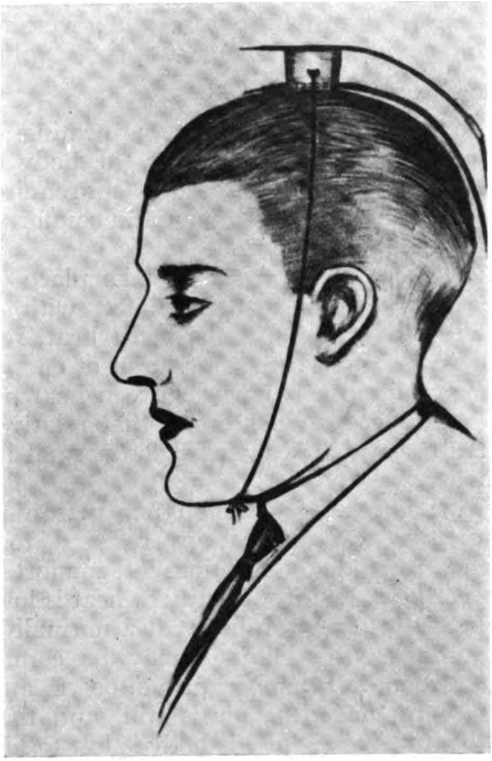


FIG. 2. THERMOCOUPLES FIXED IN POSITION FOR TEMPERATURE MEASUREMENTS.

It was evident from these experiments on helmets that the properties of metallic surfaces could be made use of for controlling the influence of the external environment in respect of radiant heat, and so protect the head against extremes of temperature, and as this was possible, then the same might presumably be done for the body as a whole in thin-walled hutments, and tentage exposed to the tropical sun. I took out with me to Egypt enough aluminium foil to carry out field tests in hutments and tents, but before describing them I must indicate certain fundamental physiological considerations which form the basis of the principles governing the effective use of insulation against heat or cold for increasing human comfort.

Physiological Considerations.

It is the usual practice, I believe, among heating and ventilating engineers to use the figure 400 B.T.U. for the body heat produced per person per hour when calculating the heat required to warm the air, or the refrigeration necessary to maintain comfortable conditions in large meeting halls or theatres.

Heat production by the body must take place so long as life lasts, for the chemical changes associated with such essential phenomena of the living state as the heart beat, respiration, and glandular activity all involve the liberation of energy in the form of heat. By maintaining a balance between heat production and heat loss, the body succeeds in keeping that relative constancy of internal temperature which is essential for normal health and the sense of well-being.

While 400 B.T.U. heat production per person per hour is a reasonable basis for the calculations referred to, it must be remembered that individual sensations of comfort or discomfort depend very much on how this quantity of heat is lost by the body. Thus it is necessary to bear in mind that a normally-clothed man, accustomed to the English climate, may be comfortably warm when sitting in a room at a temperature of 60° F. and 50 per cent. relative humidity provided the air is still, and that under such conditions the heat produced by his body is lost to his environment in approximately the following percentage proportions: 45 per cent. by radiation, 31 per cent. by convection and conduction to the air, and 24 per cent. by the evaporation of moisture from the lungs and skin.

Although the total loss of heat may balance body heat production under different conditions of temperature, humidity and air movement, it is a matter of common experience that any gross disturbance of this proportionate loss of heat is associated with sensations of discomfort. Inasmuch as the four physical characteristics of the environment, the dry-bulb temperature, the relative and absolute humidity, radiation to and from the surroundings, and air movement together determine in what proportions body heat can be lost, by radiation, convection and evaporation of moisture, it follows that each of these physical factors needs to be considered, and if any one of them shows wide variation from the conditions which we associate with comfort, then that factor needs particular attention.

I think an illustration will make this matter clear. Most of us have experienced the sudden sensation of discomfort and oppressiveness which is felt on entering a tent exposed to hot summer sunshine, or on going into a corrugated-iron or wooden hut. The tent flaps or the doors of the huts may be open and still the same sensation is felt. If temperatures are taken inside the tent or huts they may not be very much greater than the temperature outside, but if, instead of taking the air temperature, we take the inside surface temperature of the tent fabric, or the galvanised-iron or wood on the side exposed to the sun, we find, at once, in the raised temperature of the internal surface, the explanation for our sensation of discomfort. Again, it is common experience that on entering a thin-walled, fireless room in winter time, a chilling sensation is experienced, out of all proportion to the difference between the air temperature in that room and in the rest of the house. In this case we have precisely the reverse of the conditions in the tent in summer, but in both cases we experience a sudden alteration in the percentage heat lost, not by convection, or evaporation of moisture, but by radiation. In the case of the tent or galvanised-iron hut in summer the inside surface temperature of large areas may easily reach 120-130° F. even in this country, and obviously such a temperature makes loss of heat by radiation from the surface of the body impossible, and converts it into a gain which can only be compensated for by increased sweating and evaporation of moisture or by fanning to help convection.

If we recall that a 45 per cent. loss of body heat by radiation is consistent with reasonable comfort,[10, 11] it is clear how important it is to study ways and means of preventing any gross disturbance of this proportionate loss, and inasmuch as metallic insulation finds its most useful field of application in controlling radiant heat I have felt it worth while to draw attention to these physiological considerations.

Metallic Insulation in Hutments.

The field tests on the value of metallic insulation in buildings were carried out in three identical galvanised-iron hutments in the desert, as shown in Fig. 3.

Hut A was lined on the inside walls and roof with 3-ply wood, spaced approximately 2 in. from the inside of the corrugated iron.

Hut B had a lining of asbestos-cement sheeting similarly fixed as in hut A.

Hut C had a lining of 3-ply wood as in hut A, but in the 2-in. air space, a single layer, or diaphragm of metallic insulation was inserted

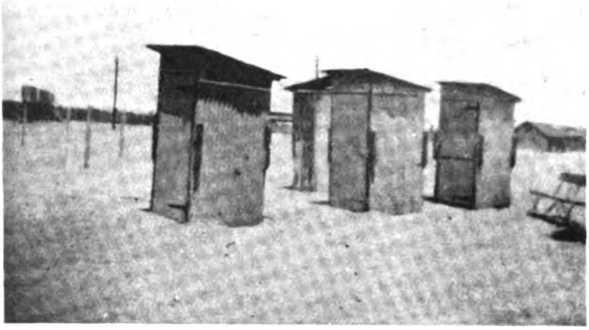


FIG. 3. HUTMENTS USED FOR METALLIC INSULATION TESTS IN THE EGYPTIAN DESERT. AUGUST 1932.

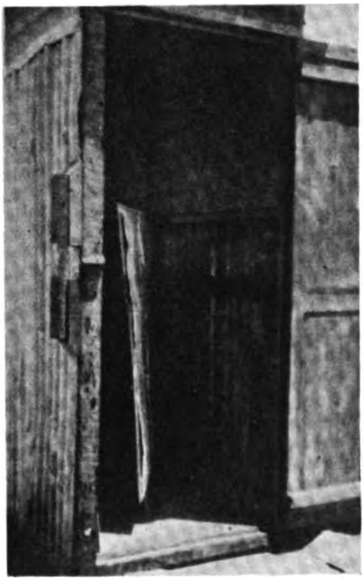


FIG. 4. HUT C, SHOWING REINFORCED ALUMINIUM FOIL DIAPHRAGM ATTACHED TO PLYWOOD PANEL.

and fixed to the plywood by wooden battens, so that an air space of ½ in. separated the inner metallic surface from the plywood (Fig. 4).

At 4 p.m. (summer time) on August 17th, 1932, the following temperatures were recorded :—

Shade temperature, 95° F.

Temperature of corrugated-iron inside surface, 127.2° F.

Surface temperature of internal walls of huts on side exposed to the sun :—

Hut A (3-ply lining), 115° F.
Hut B (asbestos lining), 112.1° F.
Hut C (3-ply and reinforced foil), 103.8° F.

Thus in hut A with the 3-ply lining only, the inner surface was at a temperature 12.2° F. less than the corrugated-iron ; in hut B, with the lining of asbestos-cement sheeting, the surface temperature was 15.1° F. less than the iron, and in hut C, with the metallic insulation and 3-ply lining, the surface temperature was 23.4° F. less than the iron.

In other words, taking the shade temperature of 95° F. as the basis, in hut A the plywood lining developed a temperature 20° F. higher than the air temperature ; in hut B the asbestos-cement sheet was 17.1° F. higher, while in hut C, with plywood and metallic insulation, the surface temperature was only 8.8° F. above air temperature.

Inasmuch as all these temperatures were well above the temperature of the human body, the lessening of the surface temperature achieved by the use of the metallic insulation was of great significance to human comfort.

At the time of these tests there was a good deal of wind, which naturally ventilated the huts, but it is significant to observe that at 5.45 p.m. on the same day, after the doors of the huts had been closed for some time, the air temperatures in the huts were recorded as follows :—

Hut A—98.6° F.
Hut B—96.8° F.
Hut C—95.0° F.

The material which I used for metallic insulation in these tests was by no means perfect, but it was the best I could obtain at that time. Actually, it consisted of embossed aluminium foil on one side of a stiff paper reinforcement, while the other side of the paper was coated with tin. The tin coating was not tinfoil, but powdered tin adhered to, and rolled flat on, the surface. The emissivity for radiant heat of the tin-coated side was about five times as great as that of the aluminium foil, and therefore the results obtained in respect of the reduction in surface temperature were not so good as they would have been had both surfaces been aluminium foil. However, the results were good enough to indicate that it was well worth-while proceeding further with the matter, not only because of the significant reduction in surface temperature which the tests proved could be obtained, but in view of the simplicity and ease of construction and the small cost of the material itself.

Apart from the results obtained, the particular value of these field tests was that they clearly indicated what improvements must be made in the metallic insulating material before it could be of use for building purposes. Thus it was evident that if reinforced aluminium foil, i.e., aluminium foil firmly adhered to both sides of some durable, handleable and flexible material, could be produced in widths of 2 ft. or more, and provided the foil was adhered with some waterproof adhesive not deleterious to the foil itself, then it would be possible to make use of the physical properties of bright metallic surfaces for increasing human comfort by controlling radiant heat. On returning to England, I did my utmost to obtain such material, but found that it was not being manufactured. As a result of further laboratory experiments with numerous adhesives and materials it became evident that if aluminium foil could be bonded to asbestos paper or asbestos felt with bitumen on a manufacturing scale, a suitable material for metallic insulation in buildings would then become available. The manufacturers hesitated to adopt the suggestion and expressed doubts that such a material would provide good insulation if used as a diaphragm in a hollow wall or air space, but a demonstration of the physical properties of metallic-foil surfaces and the following laboratory tests on insulated panels overcame these doubts.

Quantitative Measurements.

Panel Model Test.—In order to demonstrate the effectiveness of the insulation, the apparatus shown in Fig. 5 was constructed. This apparatus consists of a galvanised-iron vessel, 6 in. square in cross-section and 7 in. high. The outer surfaces of the vessel are painted matt black and the test panels are held in contact with each of the four vertical faces by means of stretched rubber bands.

Water is kept boiling inside the vessel by means of an electric bulb or heater, and from time to time during the test the surface temperatures of the outer surfaces of the panels under comparison are taken by means of thermometers stuck to the surfaces with plasticine. The framework of each panel is of identical construction, namely, two sheets of asbestos-cement sheeting spaced 1 in. apart by means of two narrow strips of wood. Each panel is sealed at the top and bottom either by glass or adhesive tape to prevent air circulation.

I have carried out a large number of tests with this apparatus with different materials in the air spaces and with single and multiple bright metallic surfaces bounding or dividing the air space, but the following test, which has been repeated with the same materials on numerous occasions during the past year, now serves not only to indicate the efficiency of the insulation provided by a layer of reinforced foil fixed so as to divide an air space of 1 in. into two layers of air of ½ in., but also to show that the insulating value

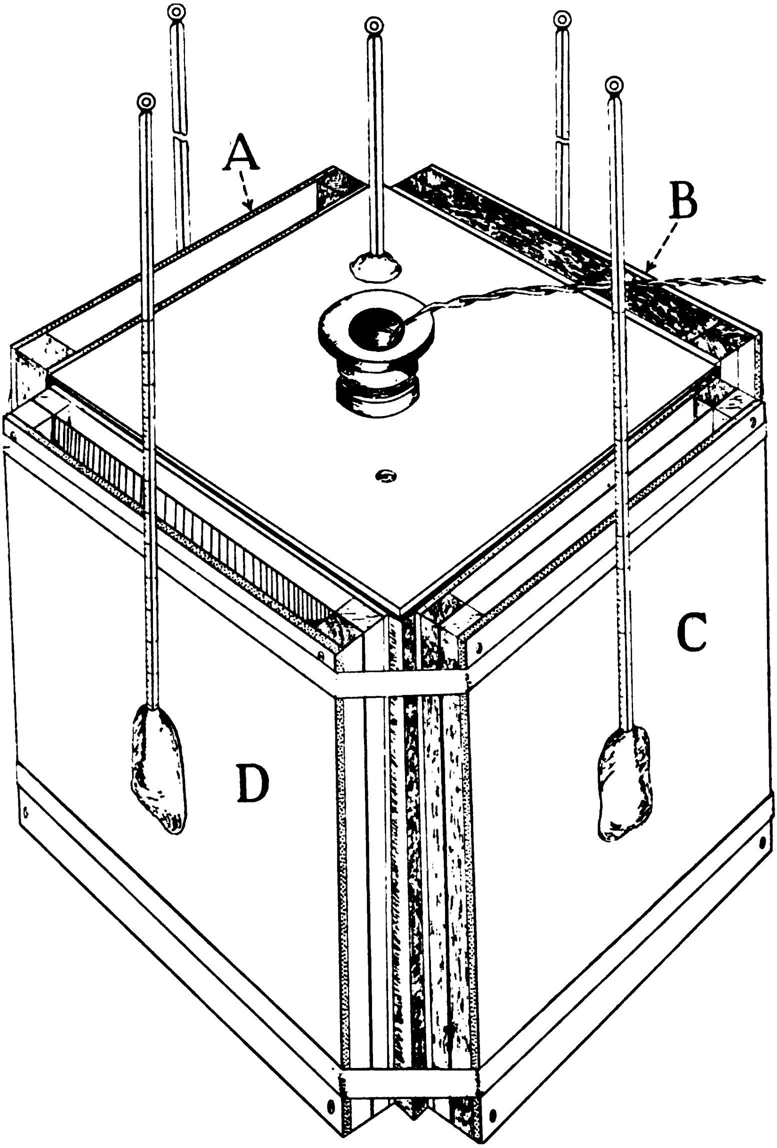


FIG. 5. APPARATUS FOR COMPARING AND TESTING DIFFERENT TYPES OF INSULATION BY SURFACE TEMPERATURE MEASUREMENTS.

of the material has not yet shown any diminution with time. More than a year ago, a test similar to the following was carried out with the same panels, and to-day the same results are obtainable on repeating the test.

Air temperature in laboratory: 69° F.

Panel A: consisted of 2 sheets of asbestos cement and 1 in. air space.

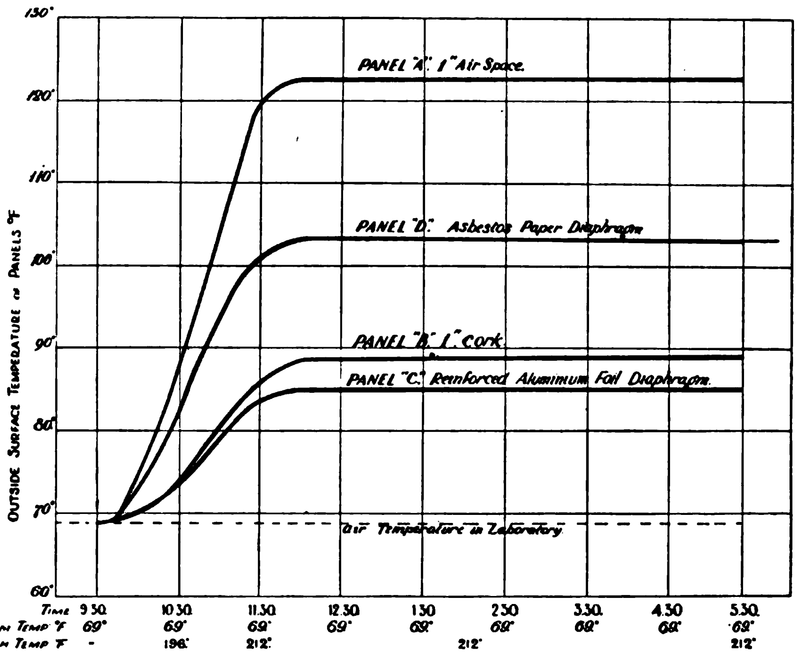


FIG. 6. SURFACE TEMPERATURE CURVES OF PANELS UNDER TEST:
PANEL A. 1 INCH AIR SPACE.
PANEL B. 1 INCH CORK.
PANEL C. REINFORCED-FOIL DIAPHRAGM.
PANEL D. ASBESTOS-PAPER DIAPHRAGM.

Panel B: same construction as A, but a 1-in. cork slab completely filled the air space.

Panel C: had the 1-in. air space divided medially by a partition consisting of aluminium foil adhered to both sides of asbestos paper by bitumen.

Panel D: had the 1-in. air space divided medially by a partition of asbestos paper only.

At 9.30 a.m. the vessel was filled with hot water and the electric heater turned on. By 12 noon the outside surface temperature of the panels had reached stability, as shown in Fig. 6, and at that time the readings were :—

Panel A: 123° F. Panel B: 88.4° F. Panel C: 85° F., and Panel D: 103° F.

The water was kept boiling in the vessel for a further 5 hours, and at 5.25 p.m. the surface temperatures were as follows :—

Panel A (air space only) : 123° F.
Panel B (1-in. cork) : 88.6° F.
Panel C (reinforced-foil diaphragm) : 85° F.
Panel D (asbestos-paper diaphragm) : 103° F.

Thus, the division of the 1-in. air space by the medially placed diaphragm of reinforced aluminium foil afforded as good an insulation against heat transference as 1 in. of slab cork, while a diaphragm of asbestos-paper having no metallic surfaces whatever, was approximately half as good an insulator as the cork.

It is, however, of more significance from the point of view of bodily comfort if these results are regarded from a different angle—namely the actual and relative rise in the surface temperature of the panels above the air temperature of the room, which was 69° F. at the time. Thus, Panel A reached stability at 54° F. above air temperature,

Panel B reached stability at 19.6° F. above air temperature, (34.4° F. less than A).

Panel C reached stability at 16° F. above air temperature, (38° F. less than A).

Panel D reached stability at 34° F. above air temperature, (20° F. less than A).

Regarding these figures in their relative values as compared with the surface temperature of panel A with the air space or hollow wall only, it is clear that by the simple procedure of dividing the air space by a single diaphragm of material having two bright metallic surfaces, the rise in surface temperature can be reduced to less than one-third, and that a non-metallic diaphragm of asbestos paper reduces the rise in surface temperature to two-thirds, i.e., a layer of non-metallic material is about one-half as good as the metallic insulation used.

In the tests with the panel apparatus, using the continuous boiling of water for the thermostatic control of the temperature of the hot faces, the panels and the metallic or other insulation are subjected to degrees of heat more severe than any likely to be met with in ordinary habitations either in this country or in the tropics. In this latter connection, it may be useful to recall that in the tests in corrugated-iron huts in the desert already referred to, when the iron registered 127.2° F. the inner surface of the plywood lining was only 8.8° F. hotter than the air temperature of 95° F. when reinforced foil of inferior quality was used as a diaphragm, as compared with the plywood surface temperature of 20° F. higher than air in the case where there was no insulation in the 2-in. hollow wall.

A moment's consideration of the structure of the panel in which the diaphragm of reinforced aluminium foil divides the air space reveals the fact that the transference of heat across the air space from the hot to the cold face is impeded by the combined action of the following factors :—

(*a*) The reflection of radiant heat back to the hot face by the first metallic surface of the reinforced foil.
(*b*) The very low emission of radiant heat from the metallic surface of the reinforced foil opposite the cold face.
(*c*) The low heat conductivity of confined air.
(*d*) The limitation of the movement of warmed air by convection and diffusion occasioned by the division of the air space by the airproof diaphragm of reinforced foil.

In practice, where insulation against external heat is desired in buildings, ships or transport vehicles, it will be found both possible and desirable to make use of the heat absorbing capacity of moving air to increase the utilitarian efficiency of the insulation still further. Thus, in a building, by permitting vertical convection currents to ventilate the air spaces, any accumulation of warmed air in the hollow walls or roof linings will be prevented, and the actual temperature of the surface of the inside wall or roof kept practically at air temperature.

A test which the Captain of the P. and O. liner, *Cathay* permitted me to carry out near Port Said serves to illustrate this. On the funnel side in one of the corridors of that liner, the surface temperature of the wall was distinctly hot to the touch, and heat radiated to the cabin opposite caused considerable discomfort. A panel, comprising an outer sheet of tin and an air space of 1 in. medially divided by a diaphragm of reinforced foil, was fixed to the hot wall of the corridor. While the top and bottom of this panel were closed with strips of adhesive tape its surface temperature was stable at 90-91° F., but when the adhesive tape covering was removed and vertical air circulation permitted in the air spaces, the surface temperature was 87.8° F., i.e., only 1.8° F. higher than 86° F., the air temperature in the corridor. Fig. 7 illustrates, in diagrammatic form, some possible sites for the use of metallic insulation in ships.

While the free circulation of air through the spaces of the insulation may be desirable in hot surroundings, the reverse will be the case in the face of extremes of cold. In the former case, it does not matter to the occupant of the room where the heat goes to so long as the surface temperature of the enclosure is not raised, and warmed air does not enter, while, in the latter, it is important that the minimum amount of heat should be lost through the walls, and therefore air circulation in hollow walls or behind panelling is undesirable, as it will prevent the retention of heat by the surface. Dufton[12] has drawn attention to the value of wood panelling for comfort, due to the fact that its capacity for heat being small, it rapidly warms up to room temperature. This is particularly the case if behind it there is a layer of metallic insulation which reduces loss of heat outwards by radiation.

It is evident from what has been said that, while in cold surroundings the value of insulation in habitations will be governed by its conductivity in terms of B.T.U. transmitted per unit area per unit time for the difference in temperature encountered, in hot surroundings the actual conductivity coefficient may not represent the true utilitarian value of the insulation, for if the construction of the walls and nature of the insulating medium permits the removal of accumulated heat by circulating air, as in the case of a diaphragm of metallic insulation in a hollow wall, then the surface temperature of the inside wall will be appreciably lower and the effective value of the insulation proportionately greater than the value calculated from conductivity data alone.

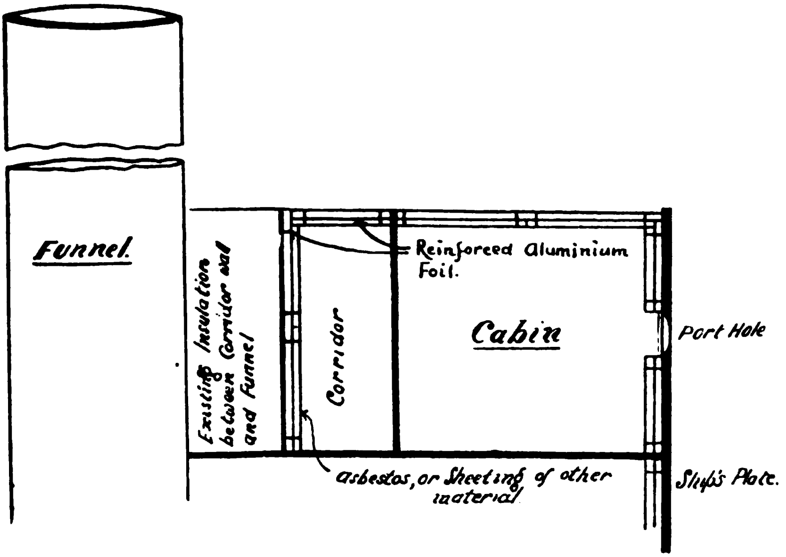

Funnel.
Existing Insulation between Corridor wal and Funnel
Corridor
Reinforced Aluminium Foil.
Cabin
Port Hole
asbestos, or Sheeting of other material
Ship's Plate.

FIG. 7. SITES FOR METALLIC INSULATION IN SHIPS' CABINS AND CORRIDORS.

It is possible that the panel testing apparatus described above might provide a convenient and reliable standard method of assessing the value of insulating materials for use in inhabited buildings, for by means of this apparatus the following information can readily be obtained :—

(*a*) The surface temperature of the insulated panel under test in relation to the surface temperature reached by identical panels without any insulating medium or filled with some standard material such as cork of known conductivity.

(*b*) The effect of convected air circulation through the insulation on the surface temperature of the panel.

(*c*) The rate of cooling of the test-panel surface after the external source of heat is withdrawn.

In regard to (*c*) it is well known that the retention of heat by building materials in hot weather may keep the inside surface temperature uncomfortably high long after the sun has ceased to warm the building, and therefore such data would be of considerable practical importance. The test panels could be of any material and the dimensions of the central thermostatically-controlled vessel modified to suit practical requirements.

In general terms, the uses of insulation against heat and cold may be divided into two categories : (*a*) where the insulation is employed for increasing human comfort, and (*b*) where insulation is required for heat conservation or the preservation of low-temperature conditions. It by no means follows that data which are suitable for use in the case of the latter are equally applicable to the former because of the physiological factors which need to be taken into account. Thus, while the living body is dynamic in the sense that continuous heat production is inevitable and a balanced loss of heat essential for life and comfort sensations determined largely by the proportionate loss of heat by radiation, convection and evaporation, meat and foodstuffs generally are static in the sense that their preservation and condition do not depend on intrinsic heat production. If the human body be completely surrounded by a heat reflecting surface, the heat balance is upset, but the reflection of its own radiation back to a piece of meat simply tends to preserve its physical state.

Housing.

In the summer of 1933, a large firm of constructional engineers in London, asked me whether it would be possible to improve the conditions inside the wooden huts used by the foremen on building sites, and I suggested that they might try the effect of a layer of reinforced aluminium foil in the air space between the wood and the inner wall-board lining. This was done in the case of a hut on a site near St. Paul's, and last winter the firm wrote to me saying that the works foreman had reported that "the hut was appreciably cooler in the hot weather, and, as regards winter, never more than one-third of the heating it previously required has been used." The firm also reported that, as compared with other wooden offices, this hut had a further advantage in that it excludes a great deal of the noise of machinery and hammering in operation on the work alongside. The sound insulation may have been primarily due to the wall-board used, but the figure one-third the heat in winter time interests me, because I have found, and Leslie found 130 years ago, that a hot vessel surrounded by a bright metallic casing spaced ½ in. away from the hot surface cooled at approximately one-third the rate of an unprotected vessel at the same temperature. Fig.8

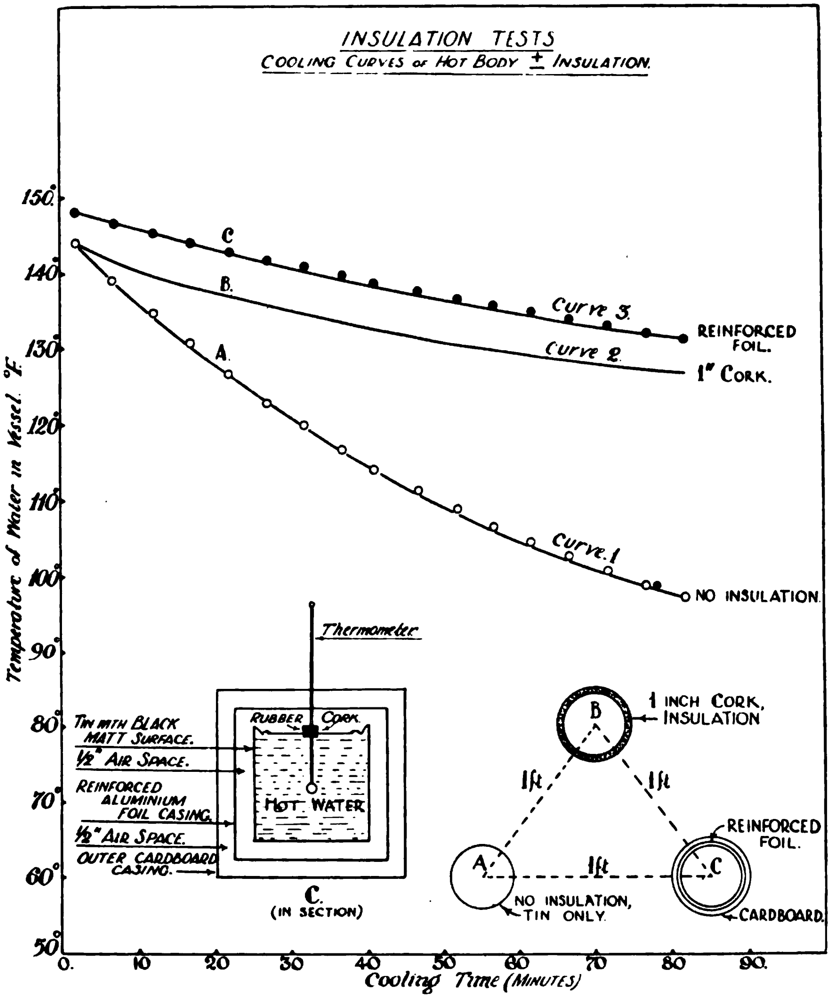


FIG. 8. COOLING CURVES OF THREE TINS OF HOT WATER :
A. NO INSULATION.
B. 1 INCH CORK CASING.
C. METALLIC INSULATION AND AIR SPACE.

shows the cooling curves of three identical tins of hot water, symmetrically placed; A exposed, B encased in 1 in. cork, C surrounded by metallic insulation.

The obvious lesson to be learnt from this practical experience is that in lightly constructed dwellings, the heating of which forms a considerable item in the family budget, the use of metallic insulation would release funds for the purchase of more and better food. If this is possible, as I firmly believe it is, then this suggestion should not only receive the earnest consideration of, but be tried by, those authorities who are responsible for the housing of the working classes in various parts of this country at the present time.

In February last, in one of the suburbs of north-west London, a very cold bedroom, built above a garage and having three outside walls, was completely lined on its inside walls and ceiling with reinforced aluminium foil tacked on to ½-in. battens so that an air space of half an inch was formed between the outer metallic surface and the plaster, while the inner bright surface of the metallic insulation was exposed to view. This particular room had previously been unfit for use in winter as it was too cold, while in summer it was very hot. While the workman was installing the metallic insulation he had to have an electric radiator in the room to keep him warm, but when the room was nearing completion he had no need for the radiator and had to open the windows in order to keep cool. The explanation for this interesting experience is that the inner bright metallic surface reflected back to his body between 80 and 90 per cent. of the heat which he would ordinarily lose by radiation to colder surroundings, e.g., plastered or papered walls capable of absorbing the radiant heat of long wave-length emitted from his skin and clothing. I understand that the installation of the metallic insulation has rendered the room comfortable both in winter and in summer. Fig. 9 shows a diagrammatic section of a tropical bungalow with metallic insulation in the roof and walls.

Tentage.

During the very hot spell which was experienced in the latter half of July this year, I carried out some tests in Army bell-tents in the camp of the University of London Officers Training Corps at Sandown, Isle of Wight.[13]

In one tent a second lining was fixed (as shown in Fig. 10) so as to provide a double lining to that half of the tent which was mainly exposed to the sun. The outer side of this inner lining had aluminium foil adhered to the surface of the Egyptian canvas of which it was made. A large number of independent observers entered this tent and were unanimous in their opinion of the comfortable coolness inside it as compared with the ordinary bell-tents near by. By means of the Moll radiation thermopile and galvanometer, I measured the surface-radiation temperature of the fabric inside the tent and found that the inner surface of the canvas of the bell-tent itself on the sunny side was radiating heat equivalent to that given out by a black body at 133.6° F. A layer of Egyptian canvas, without any aluminium foil, spaced 3 in. away from the canvas of the bell-tent reduced this to 97.6° F., while the inner fabric surface of the aluminium foil covered lining only registered 83.7° F. The shade temperature at the time was 81° F. Inasmuch as it is customary in the tropics to use double tents, it would be a relatively simple matter to make effective use of metallic insulation by having the outer side of the inner tent covered with aluminium foil firmly adhered to the canvas.

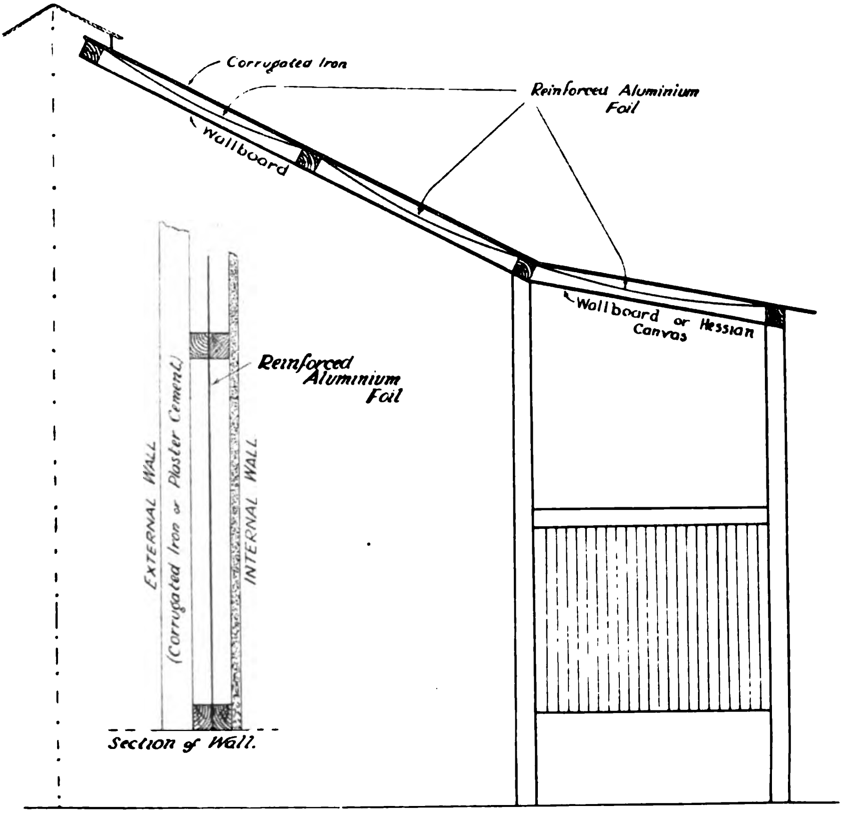

Corrugated Iron
Reinforced Aluminium Foil
Wallboard
Wallboard or Canvas Hessian
Reinforced Aluminium Foil
EXTERNAL WALL
(Corrugated Iron or Plaster Cement)
INTERNAL WALL
Section of Wall.

FIG. 9. SECTION OF TROPICAL BUNGALOW SHOWING METALLIC INSULATION IN ROOF AND WALLS.

It is worthy of note that less than 1° F. difference in dry-bulb air temperature was observed in the ordinary bell-tents with the door flaps open and brailing up, and the tent with the reinforced foil lining, but the difference in comfort sensation was most marked. Free ventilation in the ordinary tents did not prevent the

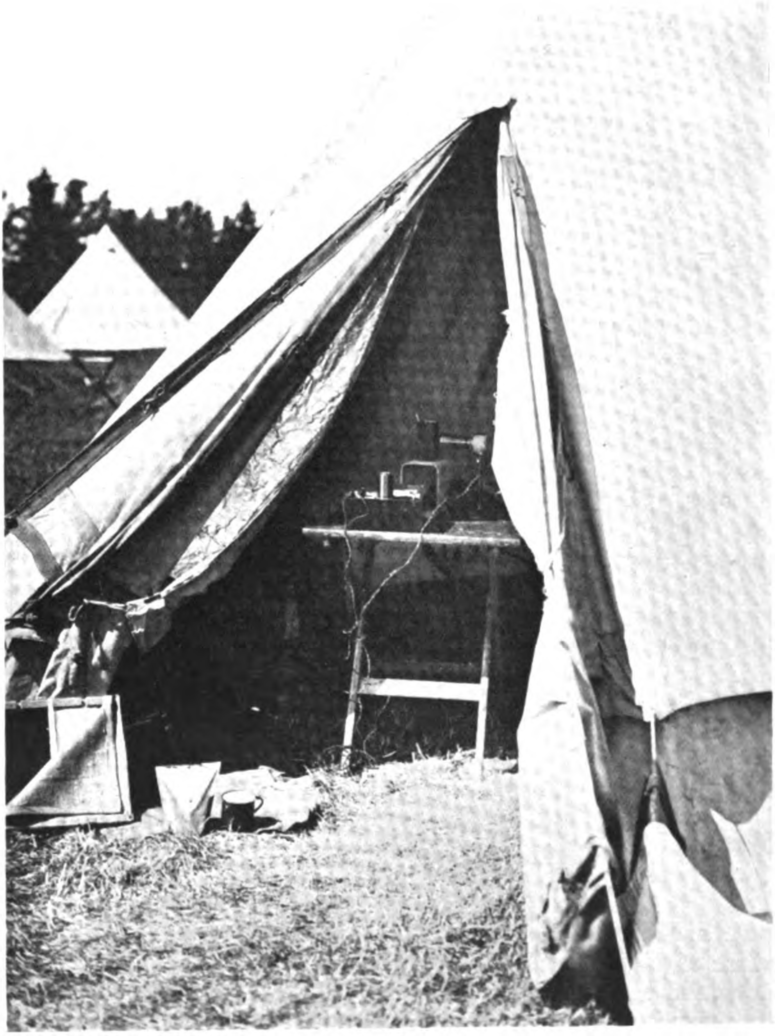


FIG. 10. BELL-TENT FOR TROPICS SHOWING METALLIC INSULATION ON OUTER SURFACE OF INNER LINING.

discomfort caused by the penetration of solar radiation and the emission of radiant heat from the heated fabric. Kata-thermometer readings were taken, but they did not appear to bear any relation to the different sensations of comfort experienced under these conditions. I think that further studies in tentage in hot and cold weather will yield very valuable information on the subject of human comfort in relation to the physical environment, and that the control of radiant heat made possible by metallic insulation will materially help the scientific investigation of this problem.

Food Preservation.

In the tropics, and also in camps in hot summer weather in this country, the preservation of food and the economy of ice are problems which have presented considerable difficulty, but from the results of the following full scale practical trials in the field, I feel convinced that the solution of these problems lies in the use of metallic insulation.

Elsewhere I have recorded experiments which were carried out in the Egyptian desert in 1932 with ordinary tea-chests converted into efficient ice-boxes by means of metallic insulation,[8] but the use of such insulation in a camp meat store has not been previously described as far as I am aware. Fig. 11 shows the store in which the meat and other perishable foodstuffs for the camp of 600 members of the University of London Officers Training Corps were kept during a fortnight of exceptionally hot weather, at Sandown in July of this year. The store was a wooden shed roofed with felt and having perforated zinc on the doors and on the side facing east. Its dimensions were approximately 8 ft. × 6 ft. base, 8 ft. high at the entrance, falling to 6 ft. at the rear. Metallic insulation of aluminium foil adhered to both sides of asbestos felt was tacked loosely on the inside walls and roof, and a few 3-ft. strips of the material were fixed over part of the perforated zinc on the east side to prevent the direct penetration of the sun's rays in the late afternoon. Thermometers were fixed by plasticine to the outside of the roof, to the wood on the inside of the roof, and on the lower surface of the metallic insulation. The following are some of the temperatures recorded :—

Date	Time (summer-time)	Surface Temperatures °F.		
		Outside of Roof	Wood inside Roof	Metallic Insulation
16.7.34	3.55 p.m.	104° F.	102.2° F.	77° F.
17.7.34	3.45 p.m.	122° F.	107.6° F.	85.1° F.
21.7.34	12.30 p.m.		104° F.	77° F.

If it had not been for the metallic insulation, the foodstuffs in this store would have been warmed by radiation from large areas of wood at a temperature 20-25° F. higher than the metallic insulation, and it must be remembered that wood has an emissivity value practically as great as a black surface.

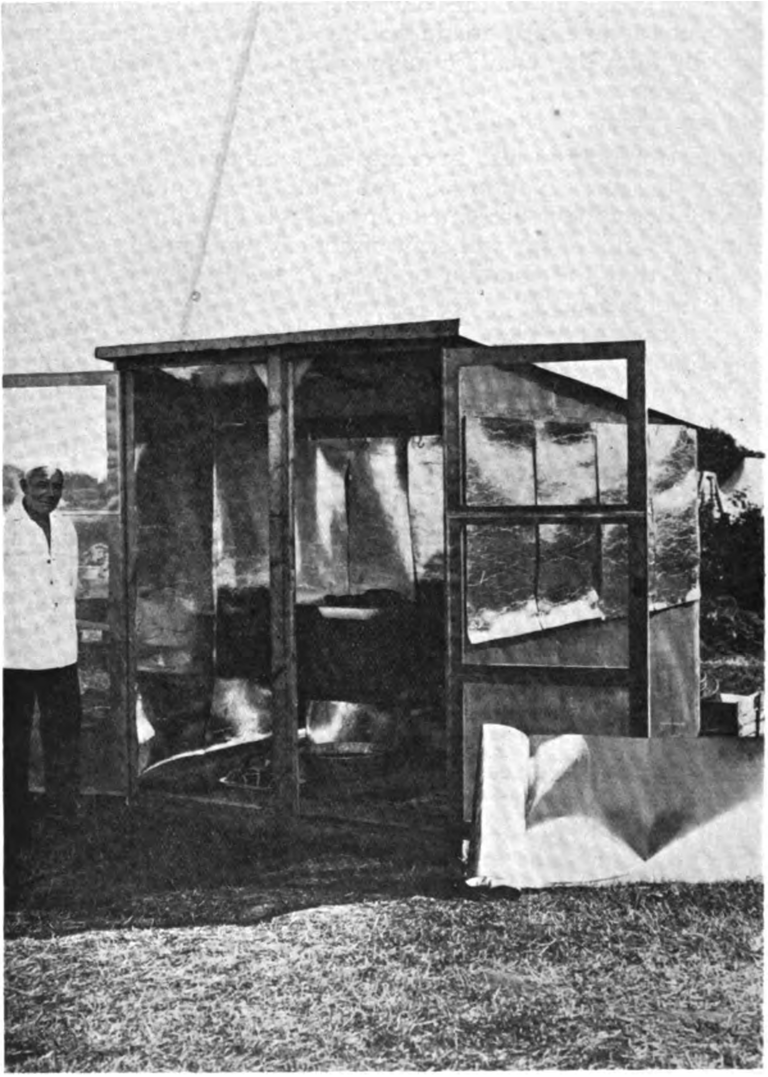


FIG. 11. CAMP MEAT STORE SHOWING REINFORCED ALUMINIUM FOIL INSULATION ; SANDOWN, JULY 1934.

The practical result of the use of the metallic insulation in this very simple way was as follows :—

The Army caterers arrived in camp prepared to purchase 3 cwt. of ice per day in order to keep the foodstuffs fresh. After fixation of the metallic insulation in the meat store and surrounding the bath which contained the ice with a collar of reinforced foil and covering it with a wooden box lined with the same material, as shown in Fig. 12, it was found that only 1 cwt. of ice was required every two days, and that even then there was sufficient left to supply the officers' mess. The foodstuffs kept perfectly fresh, the absence of flies was a noticeable feature, dripping poured into a tea-chest in the store set, and the professional cook observed that he was able to keep the meat as well as if he were in an hotel.

The amount of material used for metallic insulation in the meat store would cost about £1. The material was cut into strips with large scissors and fixed in position by two amateurs in two hours. The saving on the purchase of ice which resulted was not less than £4, and the reinforced foil was in as good condition at the end of the fortnight as at the beginning. The durability of the asbestos felt reinforced foil used was anticipated, as previously similar material had withstood an all-weather test in the open for three months without showing any deterioration of the metallic surfaces.

I have thought it desirable to give a full account of this large scale practical trial in view of the peculiar difficulties in the way of food preservation during hot weather, particularly in camp, and because the results achieved by the use of metallic insulation in the simple way described above have proved how these difficulties can be easily overcome.

Other Types of Metallic Insulation.

In this paper I have naturally dealt with the various aspects of the subject which I have studied personally both in the laboratory and on a practical scale, but it would be doing an injustice to many other workers in this field were I not briefly to refer to certain advances in metallic insulation which have been made in recent times.

A form of metallic insulation consisting of almost the thinnest aluminium foil which can be manufactured has been on the market for several years. The distinctive feature of this insulation is that, by a system of crumpling, the foil tends to support itself in an air space.[14, 15] Usually three layers of crumpled foil are employed per inch of insulation, and if carefully installed, this is approximately as good as an inch of cork. Where lightness is essential this type of metallic insulation has distinct advantages.

For the past year or so there has been in use in the United States a form of insulation comprising aluminium foil adhered to one or both sides of a thick kraft paper.[16] This material is used in buildings in precisely the same way as the asbestos paper or felt reinforced foil produced in this country. According to reports, the American explorer, Admiral Byrd, used the kraft paper metallic insulation in his hut in the Antarctic and found that it provided effective insulation against extremes of cold.[17] The walls of his hut had a

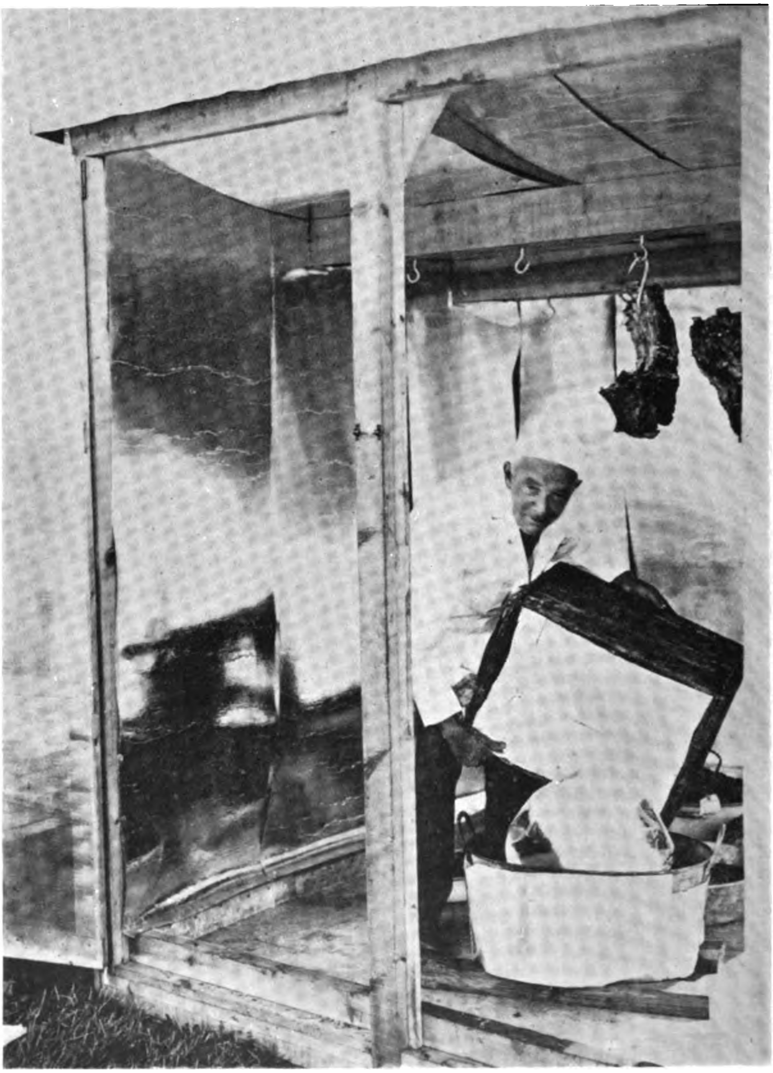


FIG. 12. STORAGE OF ICE IN CAMP MEAT STORE.

bright metallic surface so that radiation losses from the clothing and skin of the occupants would be largely compensated for by the reflection of heat back to their bodies. In this connection it may be recalled that experiments at the Building Research Station[18] have shown that by lining the inner surfaces of the external walls of a room with aluminium foil faced wallpaper, an absolute saving of heat amounting to 8 per cent. can be achieved, but the effect of the reflection of their own body radiation back to the occupants of the room would, in practice, in all probability permit of a still greater reduction in the amount of artificial heat required to maintain conditions of comfort.

There are many uses for metallic insulation for household purposes, horticulture, agriculture, passenger transport vehicles, and in industry, but time and space do not permit me to deal with these matters, nor with various technical researches which have been carried out in this country and abroad on more complicated constructions and more difficult problems of insulation than I have studied. Those interested in these matters will find a great deal of valuable information in the publications given in the list of references, and in many of the papers referred to, particularly those in American technical journals, additional references will be found.

Conclusion.

One hundred and thirty years have elapsed since John Leslie first demonstrated by laboratory experiments with metallic surfaces the fundamental facts and principles which are finding to-day their field of useful application in the service of mankind in the various constructions and for the several purposes mentioned in this paper.

I feel I owe Leslie an apology for not reading his original publication at the outset of my investigations, but I think if I had done so, I might have said to myself—the experiments have been done : the facts and principles are known. Their application must surely have been tried and found wanting, or else bright metallic surfaces would be in general use. I now find that I have quite unwittingly repeated many of Leslie's experiments, but with this difference in procedure, namely that at each stage I have checked up the experiment in the laboratory by a full-scale test under conditions where the finding might be of service to man. Moreover, inasmuch as each practical trial has not only borne out the laboratory results, but suggested new problems for research, encouragement to proceed further has continually been added, and the stimulus of the field results has not been limited in its effect to me, but has reacted on those who saw the demonstrations, and in particular on certain manufacturers who were thereby convinced that materials should be made available to the public in such a form, and at such a cost, as would make it practically and economically possible for them to make use of the physical properties of bright metallic surfaces for insulation against heat or cold.

REFERENCES.

[1] Leslie, John (1804). "An Experimental Enquiry into the Nature and Propagation of Heat." London, J. Mawman.

[2] Tredgold, T. (1824). "Principles of Warming and Ventilating Public Buildings." London, Josiah Taylor.

[3] Tyndall, John (1880). "Heat a Mode of Motion." 6th edition. London, Longmans.

[4] British Patent Specification No. 3792. 1884.

[5] U.S.A. Patent Specification No. 294,780. 1884.

[6] British Patent Specification No. 124,609, 1918, and U.S.A. Patent Specification No. 1,306,281, 1919.

[7] Crowden, G. P., and Hetherington, M. (1933). "A Comparative Study of the Physiological Effects on Children of School Heating by Hot Water Radiators and by Radiant Heat from Electric Ceiling and Wall Panels." *Journal of Hygiene*, Vol. 33, No. 2, p. 151.

[8] Crowden, G. P. (1934). "Insulation against Heat and Cold for Human Comfort." *The Lancet*, Jan. 6th, p. 37.

[9] Crowden, G. P. (1934). "The Practical Value of Physiology to Industry." *The Human Factor*, Vol. 8, No. 2.

[10] Aldrich, L. B. (1928). "A Study of Body Radiation." Smithsonian Misc. Coll., Vol. 81, No. 6.

[11] Martin, C. J. (1930). "Thermal Adjustment of Man and Animals to External Conditions." *The Lancet*. Sept. 30th, p. 561.

[12] Dufton, A. F. (1931). "The Warming of a Room." *Philosophical Magazine*, Vol. 11, June 1931, p. 1233.

[13] Crowden, G. P. (1934). "The Use of Bright Metallic Surfaces for increasing Human Comfort in the Tropics." *Engineering*, Oct. 12th, p. 395.

[14] Schmidt, E. (1927). "Wärmeschuz durch Aluminiumfolie." *Zeitschrift des Vereines Deutscher Ingenieure*, Vol. 71, Oct. 1927, p. 1395.

[15] Mason, R. B. (1933). "Thermal Insulation with Aluminium Foil." *Industrial and Engineering Chemistry*, Vol. 25, No. 3, p. 245.

[16] *Heating and Ventilating*, Nov. 1933, p. 47.

[17] *The Aerologist*, July 1934, p. 21. Also *Architectural Record*, July 1934.

[18] Dufton, A. F. (1934). "Metallic Wallpaper." *Journ. Inst. of Heating and Ventilating Engineers*, July 1934.

Other references not specifically referred to in the text :—

[19] Dufton, A. F. (1933). "Thermal Insulation of Thin Roofs." *Journ. Inst. of Heating and Ventilating Engineers*, July 1933.

[20] Dufton, A. F. (1933). "Note on Metallic Insulation." *Ibid*, Sept. 1933.

[21] Thompson, T. O. (1934). "Troopship Temperatures and Suggested Methods of Improvement. Insulation by Aluminium Foil Sheeting." *Journ. R.A.M.C.*, Vol. 62, No. 2, p. 85.

[22] Box, T. (1868). "A Practical Treatise on Heat." London, Spon, pp. 168-9.

[23] Gard, J. S. F., and Robinson, R. S. (1930). "The Insulation of Heated and Cooled Surfaces." *Journ. Soc. Chemical Industry*, Vol. 49, No. 10, p. 125.

[24] Woolrich, W. R., and Holdridge, L. (1930). "Heat Transfer Constants and Applications of Heat Transfer." *Heating, Piping and Air Conditioning*, Vol. 2, No. 2, Feb. 1930, p. 127.

[25] Schad, L. W. (1930). "Insulating Effect of Successive Air Spaces Bounded by Bright Metallic Surfaces." *Heating, Piping and Air Conditioning*, Vol. 2, No. 11, Nov. 1930, p. 957.

[26] Queer, E. R. (1931). "Importance of Radiation in Heat Transfer through Air Spaces." *Heating, Piping and Air Conditioning*, Vol. 3, No. 11, Nov. 1931, p. 960.

[27] Rowley, F. B. (1934). "Insulating Value of Bright Metallic Surfaces." *Heating, Piping and Air Conditioning*, Vol. 6, No. 6, June 1934, p. 263.

[28] Queer, E. R. (1934). "Metallic Heat Insulation." *Heating and Ventilating*, Oct. 1934, p. 22.

[29] Grabham, G. W. (1921). "Some Factors in Thermal Sanitation in the Tropics." *Journal of Hygiene*, Vol. 19, No. 3, p. 245.

DISCUSSION.

The President said that Dr. Crowden had given an intensely interesting lecture, and was to be congratulated on covering a very wide field in a remarkably short time.

Mr. Alcwyn A. Jones thanked Dr. Crowden very much for his introduction to a comparatively new form of insulation. On a previous occasion, he said, he had suggested the desirability of studying the works of the old physicists, as they had discovered so many of the principles of modern practice. It was interesting to find that Dr. Crowden, after a great amount of valuable research, had discovered the desirability of so doing, for some of his work, as Dr. Crowden himself had stated, had already been done by Leslie 130 years ago.

The introduction of metallic insulation raised the question of whether the study of the porosity of building materials had been sufficiently considered in connection with the heat transmission problems. It appeared to him that the use of metal in the construction of a building would reduce the porosity and consequently improve the temperature of the rooms. He thought at one time that the Building Research Board were contemplating a thorough investigation on the subject of porosity, when they issued their Special Report No. 4, but he had not seen any further progress in that direction.

There was no doubt that the use of aluminium foil had insulating properties, but as a heating and ventilating engineer he was disappointed that Dr. Crowden did not give the coefficient of conductivity of the different types of insulation used in his tests. Cork had a coefficient of 0.27 B.T.U./sq. ft./°F./per hour, and the figures for the other types would be valuable.

It was known that the emissivity coefficient for water was high, so that it necessarily followed that, should condensation form on the aluminium foil, its value as an insulator would be reduced. In view of the fact that the reinforcing felt was in contact with the foil, any possibility of moisture in the felt would be detrimental.

There had been a large number of experiments on the subject, and one investigator had stated that the emissivity of aluminium foil varied with the same material, and emphasised that its polish and character were not always uniform and were affected by dust or other foreign material having high emissivity. It was desirable that the foil should be bright and clean, and tarnishing obviated. Tests had been made with lacquer as a finish on the surface which gave a coefficient of 0.245. Steel plates with ½-in. air spaces had also given coefficients lower than or about the same as cork. In America an all-metal insulation was employed formed of sheets of black steel, which when used in the form of pipe covering equalled

85 per cent. magnesia covering at high temperatures and was better than cork at lower temperatures. One form had been produced, in fact, with a coefficient of conductivity of 0.195. That brought him back to the question of porosity, and he wondered whether the advantages gained by metallic insulation were partly due to the reduction of porosity.

Mr. Freeman Horn asked if Dr. Crowden had discovered whether the reflectivity plus the emissivity added up to 100 ; in other words, whether a material which had a 90 per cent. reflectivity of heat had a 10 per cent. emissivity, or alternatively, if that was not the case, whether any treatment which improved the heat reflectivity decreased the emissivity in the same proportion. He was led to that question by the experiment in which Dr. Crowden showed that whereas a bright metallic surface had a very low emissivity, if one put a transparent varnish on it, which did not make the light reflectivity materially worse, the effect of putting that transparent varnish on the bright metallic surface was to make the heat emissivity go up. He would like to know if Dr. Crowden had discovered that it also reduced the heat reflectivity. In the case of reflected light it had practically no influence at all, but he would be interested to know whether it had a greater influence on the heat reflectivity.

Mr. E. B. Edwards congratulated Dr. Crowden on his excellent paper, but was surprised that he had not referred to experiments carried out by Professor E. Schmidt ; personally, he thought it was primarily due to that gentleman that a metallic insulation became a practical proposition and not merely a scientific experiment. An article by Professor Schmidt describing that metallic insulation was published in *Engineering Progress* in 1928.

As mentioned in the paper, the failure of previous attempts had been chiefly due to the difficulties of producing a bright metallic surface which would maintain its high heat-reflective power over a period of time and of eliminating the influence of metallic conduction by the sheet. Professor Schmidt found that by the use of aluminium foil those difficulties were overcome, and he put forward practical constructions for applying a metallic insulation by means of parallel layers of aluminium foil spaced about 1 cm. apart, that distance being found to be the most suitable. That construction was, he believed, used for practical insulation work in 1927, and during 1928 was fairly widely adopted on the Continent.

The construction using plain layers of foil could be applied without much difficulty to straight surfaces or lengths of straight pipe, but it was a very different matter when it came to irregular or irregular curved surfaces, such as were found in most insulation work. The insulation of such surfaces was simplified by Dr. Dykerhoff when he put forward the use of layers of extremely thin *crumpled* foil, as referred to in the paper. By that means the various layers of foil automatically spaced themselves without the use of distance pieces, whilst conduction through the metal itself was negligible owing to the thinness of the foil and the fact that the layers touched only at irregular intervals. It was this crumpled system which had made a metallic insulation possible for all the classes of work to which it had been applied in this and most other countries of the world during the last five or six years. In this country tests were carried out by the National Physical Laboratory at Teddington, in February 1928, on a pipe insulated with parallel layers of foil spaced about three-eighths of an inch apart, whilst similar tests by testing authorities abroad were made in 1926.

Dr. Crowden referred to the insulation of a room in north-west London where a workman had to turn off the electric radiator and open the window to keep cool. Although personally he was a great believer in the efficiency of metallic insulation, he did not think that heating contractors should worry too much, as hot-blooded people did not seem to thrive in our British climate.

Mr. L. A. Baines asked if Dr. Crowden had carried out any experiments on surfaces which had been hot-sprayed with metals such as aluminium, and in that connection whether it would be of any value actually to hot-spray pipes carrying hot water—whether there would be any reduction in the emissivity of such pipes.

Colonel S. F. Newcombe said that Dr. Crowden mentioned in his paper an obvious lesson taught by practical experience, namely that in lightly constructed dwellings the heating formed a considerable item in the family budget. In the *Sunday Express* a week ago there was an article by James Douglas showing that poor people with an income of £2 10s. a week were spending 2s. 6d. to 3s. a week on fuel. It must be admitted, of course, that that probably included cooking, but on a capital basis 2s. 6d. to 3s. a week represented £130 to £156. If houses were properly insulated on an economic basis, as they should be, a very considerable reduction in that £130 capital could be effected. The slight extra cost of insulation might be put at £5 to £10 per house, but the saving to the individual would be many times greater. He did not know whether any heating and ventilating engineers possessed data on the subject, but it might be well worth following up, because it would mean a saving not only to the poorer classes but also to the ratepayers. The more it was possible to reduce the costs of living in houses and increase human comfort, the less would the individual have to pay, and in the end the ratepayer would pay less also. The Ministry of Health might indicate to local surveyors a figure of say 0.15 to 0.20 as a reasonable one for air transmission in roofs.

The President said Dr. Crowden had given a great many practical examples of how the particular insulating material with which he had dealt could be used, but he had not given very many practical examples of how it could be used by the heating engineer. It would be of interest to know whether he could give any practical examples of how it could be used for insulating boilers, for example, and pipes, the backs of panels, and so forth. It would also be interesting to hear something about the cost of such insulation.

He had been wondering whether the bright condition of the aluminium foil was likely to deteriorate in the course of time, and whether it would deteriorate more or less if it were enclosed within two layers of outside covering. He would be interested to know what might be the effect if a considerable layer of dust got on the inside ; i.e., if the foil were placed in an air space between two outer surfaces, and in the course of time dust happened to form on those surfaces, whether the efficiency would be very seriously impaired. There was also the question of what effect damp might have on it.

Dr. Crowden had given a very interesting lecture, and the Institution was greatly indebted to him for spending the time he had on preparing it. After Dr. Crowden had replied to the various questions raised, he would be pleased if any members cared to come to the platform and obtain a closer view of the materials and appliances there displayed.

Dr. G. P. Crowden, in replying to the discussion, said that Mr. Jones had raised the question of conductivity tests. A number of tests had been done by the National Physical Laboratory, the Building Research Station and certain large industrial concerns who had research laboratories. In the case of the tests at the National Physical Laboratory, it was found that a panel a yard square with a 1-in. air space divided medially by the reinforced foil had a heat transmission of 0.25 B.T.U./hr./sq. ft./1 °F. difference in temperature between faces, but the fact had to be taken into account that the panel was made up of one face of asbestos sheeting and another of wall-board and, allowing for the conductivity of those two layers of material, the improvement due to the division of the air space by the metallic insulation must have been equivalent to the insertion in the 1-in. air space of insulation having a thermal conductivity of 0.3 or thereabouts. In the case of a test with very low temperatures—actually solid CO_2—the result obtained, not at the National Physical Laboratory but elsehwere, varied between 0.26 and 0.30 with a mean value for all the tests of 0.29 B.T.U./hr./sq. ft./°F./inch. At the Building Research Station, a corrugated asbestos-cement roof with an under-layer of metallic insulation, not on asbestos but on paper, the average transmission coefficient over a number of days, calculated from the input of heat necessary to maintain 65° F. inside the room with temperatures ranging from 26° to 54° F. outside was about 0.42, but where there were two layers of the material, spaced ½-in. apart, the coefficient was 0.20 as compared with the roof of asbestos-cement only, which had a transmission coefficient of 1.50 B.T.U./sq. ft./hr./°F. These data had been reported by Mr. Dufton in the *Journal of the Institution of Heating and Ventilating Engineers* some months ago (see reference 19).

Mr. Jones also raised the question of the effect of dust. A thick layer of dust would have a considerable effect, because, being non-metallic, its particles would emit or absorb as much heat as a black surface for the temperatures under consideration. In the case of a roof structure dust was unlikely to settle on the under-face of the metallic insulation, and even if it settled on the opposite face one would still be making use of either the high reflecting properties or the low-emitting properties for heat insulation according to whether the external conditions were cold or hot. In either case the metallic insulating diaphragm would produce a considerable improvement over the mere medial division of the air space by a non-metallic diaphragm. Should something cause the total deterioration of the metallic surface, there would still be insulation substantially equivalent to half that of 1 in. cork ; the tests with the panel model with the non-metallic diaphragm of asbestos paper proved that. Provided that the initial cost was not excessive, therefore, the insulation, even if it deteriorated to the extent of becoming non-metallic, would still be a material improvement over a simple hollow wall or air-spaced roof structure. He did not think, however, that in a coal-fired boat, for instance, metallic insulation would be much use round the boilers, because of the accumulation and penetration of dust.

Mr. Jones had referred to all-steel insulation. He knew that this had been proposed but had no knowledge of the durability of the metallic surface. Metallic insulation using stainless steel might be possible, but the cost would probably be considerable. A tinned-iron sheet was good so long as the metallic coating remained bright, but a considerable quantity of heat could be conducted along the sheet, whereas a very thin foil, as Mr. Edwards pointed out, could conduct very little heat because of the very small body of material. In regard to the question of porosity raised by Mr. Jones, he did not feel competent to deal with the matter.

Mr. Freeman Horn had asked whether the reflectivity and emissivity coefficients of the various surfaces tested by the radiation thermopile added up to 100. He did not wish to make a definite statement in reply to this question because he felt that a good deal of further work was required to be done on the emissivity and reflectivity characteristics of materials for invisible radiant heat. A white surface certainly behaved very differently towards visible radiation as compared with invisible radiation. For the former it had a high reflectivity but for the latter a low reflectivity and high emissivity. The Building Research Station had dealt with the reflectivities of building materials in respect of solar radiation,* but he had not been able to find coefficients of reflectivity for radiations corresponding to temperatures of 100° to 200° F. in any of the reference books, except perhaps in Leslie's.

Mr. Edwards had referred to Professor Schmidt, of Germany. Although he had not mentioned his name in the paper, in the bibliography at the end Mr. Edwards would find a reference to Dr. Schmidt's original paper, which appeared in the *Zeitschrift des Vereines Deutscher Ingenieure* in 1927, and in which a full description of the crumpled-foil system of insulation was given. There could be no doubt that Dr. Schmidt had done a great deal to draw attention to the value of aluminium foil, and it was surprising to find that the widths of the air space given by Dr. Schmidt and others as desirable between the concentric septa or cases of metallic foil were substantially the same as those which Leslie had found in 1801 to be most effective. Leslie laid great stress on the half-inch air space, which from the practical point of view and also from laboratory tests appeared to be the most effective division, and that width was not substantially different from a centimetre between the concentric cases round the hot body or hot pipe.

The crumpled-foil system of metallic insulation was, as he had said, of distinct advantage where lightness was essential, but it did not appear to be any more effective than the simple division of an air space either by a layer of foil alone, which was impracticable in actual use owing to its fragility, or the division of an air space of 1 in. by a layer of reinforced aluminium foil, i.e., foil which had been fixed to some durable and workable material which, until the last year, had not been available in this country.

Mr. Baines had raised the question of hot-sprayed metal. Spraying would have obvious advantages in certain places which would otherwise be inaccessible, and it seemed as good as aluminium paint from the point of view of its low emissivity, but he could not be dogmatic about it ; it depended on the number of coatings. One coating might cost so much, and three a great deal more, and whether there was a proportionate change in the physical properties of the surface he was not prepared to say.

Colonel Newcombe had referred to the cost of heating in houses and that economy might be effected by adequate heat insulation. Personally, he thought the tests and trials which had been carried out showed that in all probability comfort conditions could be maintained at less cost than was occasioned by attempting to heat the whole building to keep one warm. If use could be made of panelling which rapidly picked up room temperature, and if metallic insulation were used to prevent loss of heat from behind the panel, one would get adequate warmth at a much less cost than by attempting to heat the whole of the brickwork which conducted the heat away or retained the heat in hot weather.

---

* Beckett, H. E. 1931. *Proceedings of the Physical Society*, vol. 43, pt. 3, No. 238, p. 227.

The questions which the President raised were rather difficult to answer. He had not attempted to study the insulation of boilers, which was a much more difficult problem than those he had mentioned. With regard to pipes, it had been said that what was gained owing to decreased rate of heat transference through the surrounding insulation might be lost by radiation owing to the increased surface area of the pipe due to the insulation. He thought, however, that when a pipe was encased in a sheath of metallic insulation spaced away from it, the effective radiating surface of the pipe was not increased ; the surface of the pipe which was giving out radiant heat had still its original area, and this heat was very largely reflected back to it. Possibly a tinned-iron outer protecting device and some internally spaced diaphragm of metallic insulation might prove a very effective means of dealing with pipes but the external casing must not be easily fractured, and aluminium sheet would be too costly while reinforced foil alone would not be strong enough. Tinned-steel sheet might provide a sufficiently durable outer casing over the metallic insulation, and he did not think the surface temperature of the casing would then materially differ from air temperature, having regard to tests which had been carried out ; but of course this was also governed by the actual temperature of the particular pipe.

The backs of panels and the effect of dust he had already referred to.

The cost of the material was, of course, a point of the utmost importance. People could not be expected to make use of insulation in buildings such as, for instance, the little galvanised-iron huts in the desert to which he had referred, if it was going to cost as much per square yard as it cost to insulate with cork at the present time. It was possible, however, and had in fact been done, to put the material in question, namely reinforced aluminium foil, on the market at a comparatively low cost compared with cork—actually considerably less than 1s. per square yard. (7d. per square yard in the case of paper reinforcement, and approximately 10d. per square yard if the foil was fixed on asbestos paper, or 1s. per square yard for foil bonded by bitumen to asbestos roofing felt.) The paper reinforced foil was not suitable for building purposes in the face of damp, as it was not waterproof, but this objection did not apply to the asbestos roofing felt reinforcement. It was only recently that attention had been given to the use of bright metallic surfaces for heat insulation in buildings, and now that the metallic material was available in a suitable form as regards width and durability, the general public could with advantage make use of metallic insulation.

The durability of the bright surface was, of course, a matter of vital importance. In such cases as the meat safe installed in the camp to which he had referred in the paper, it did not matter whether the material was of any value at the end of the camp ; it had achieved its purpose by saving the caterers expenditure on ice and by contributing to the enjoyment and health of the troops by preserving the foodstuffs, and had paid for itself five times over. In buildings, on the other hand, the length of life must be considerable ; but, having regard to the fact that tests showed that a single non-metallic diaphragm provided insulation equivalent to half that of 1 inch cork, and that the new metallic material could be obtained at about a third the cost of cork, it was worth installing even if the metallic surfaces did deteriorate after a certain number of years. On the other hand, tests had been carried out which showed that a material with a surface of aluminium was very resistant in character. Personally, he had never seen a dull piece of cigarette foil. He had tried his utmost to find some tarnished aluminium foil, and the worst stuff he had been able to find was a piece of aluminium sheeting which had been exposed for a couple of years at the docks. This showed no appreciable increase of emissivity of one surface as compared with the other which was bright, and certainly nothing which would affect its utilitarian value to any notable degree in the type of construction in question ; it might do so where the conservation of every single B.T.U. was a matter of vital importance, but he did not think it would impair its heat-insulating value for ordinary building purposes. He had had on test for some weeks strips of material in caustic soda, in various acids, in sulphur-dioxide solution and in sulphuretted-hydrogen solution but, apart from the solution of caustic alkali, none of the solutions rapidly affected the surface. Exposure to water for an indefinite period did not affect the felt reinforcement, although of course, it would affect the paper reinforcement. The felt was really a waterproof roofing felt and immersion in water did not detach the metal foil and had no effect on its surface brightness. Only time could prove whether or not these materials did deteriorate in the course of years to any appreciable extent when in position in a wall. It was unlikely that the surface would become coated with moisture, because in all probability the actual metal itself would be at the temperature of, or a little warmer than, the air, so that condensation would not readily take place on it. He had put a strip of the material over his car radiator last summer when there was very heavy dew, and although there were drops of dew on the hood and the bonnet there did not seem to be any on the metallic surface. He could account for that only by the fact that the high-emitting properties of the hood and bonnet caused them to drop in temperature, so that condensation formed, whereas the metallic material practically kept at air temperature the whole time and was not losing radiant heat to any extent, and so condensation on it did not occur. Even if moisture should accumulate on the material, however, there still remained in the construction proposed the insulating effect of an air-proof diaphragm dividing an air space.

In conclusion he hoped that nothing, economic or otherwise, would stand in the way of the use, both at home and abroad, of bright metallic surfaces for the purposes which had been described.

On the motion of *Mr. A. B. Potterton*, a hearty vote of thanks was accorded to Dr. Crowden for his paper, and the proceedings then terminated.

THE WARMING OF WALLS

By A. F. DUFTON, M.A., D.I.C.

CORRECTION.

We regret that in the three mathematical expressions on page 417 of the last issue, by a misinterpretation of the final proof, the position of the $^{-2}$ power was added at the end of the power of e instead of $(2n + 1)^{-2}$. Will members please make the correction.

NOSE-OPENING RAYS

By SIR LEONARD HILL, M.B., F.R.S.

COMMUNICATED

In seeking to refute me Mr. A. F. Dufton[1] cites experiments published by Winslow, Greenburg and Herrington. These experiments were made by the same method as that employed by Dufton and Bedford[2] and were published in the *Amer. Journal of Hygiene*, 1934, Vol. 20, p. 195. I pointed out in the paper which I read at the annual meeting of the Institution, 1934, that this method is one which is too insensitive to yield results. If, in the method of these authors, one nostril of the subject be connected with a recording instrument and the other left open for breathing, the mouth being kept shut, then the airway of the open nostril can be reduced even by five-sixths before the character of the quiet respiration of the resting subject is significantly altered. Moreover, there is a balance between nose-closing and nose-opening rays. If the nose-closing source is made far the stronger, then the nose-opening rays can have no effect.

To obtain evidence of nose-opening rays I use the following procedure. A small electrical heating unit measuring about 4 in. × 1½ in., is set up in a stand, and by the side of it is placed a small solid tungsten rod arc. The heater gives off about 14 times more energy than the arc, as shown by a thermopile and galvanometer. The subject sits facing the two sources, which are placed about 1½ to 2 ft. away. A length of corrugated rubber tube, such as used for oxygen breathing apparatus, is fastened by a chain and hook tightly round his, or her, body. This tube is closed at one end and at the other connected by a length of rubber tubing with a recording tambour, which is set to write on a smoked drum. A screw nose-clip (this and the corrugated tube are obtainable from Messrs. Siebe Gorman Ltd., London) is placed on the subject's nose and tightened until breathing is made slightly difficult. The right degree of adjustment of the nose-clip is important. The eyes of the subject are blindfolded or kept shut. The sources of heat and light are at the start screened-off from the subject. The respiration is now recorded and when a record, normal under the conditions, has been obtained, the screen is removed. With the subject's face exposed to both sources, the respiration continues unchanged. The arc is now screened-off, and in most subjects it will be found that the respiration becomes more difficult and mouth breathing has to be resorted to. As soon as the arc is allowed to act again the respiration returns to the normal character.

---

[1] *Journ. Inst. Heating and Ventil. Eng.*, Oct. 1934, Vol. 2, p. 345.

[2] *Journ. of Hygiene*, Vol. 33, p. 476

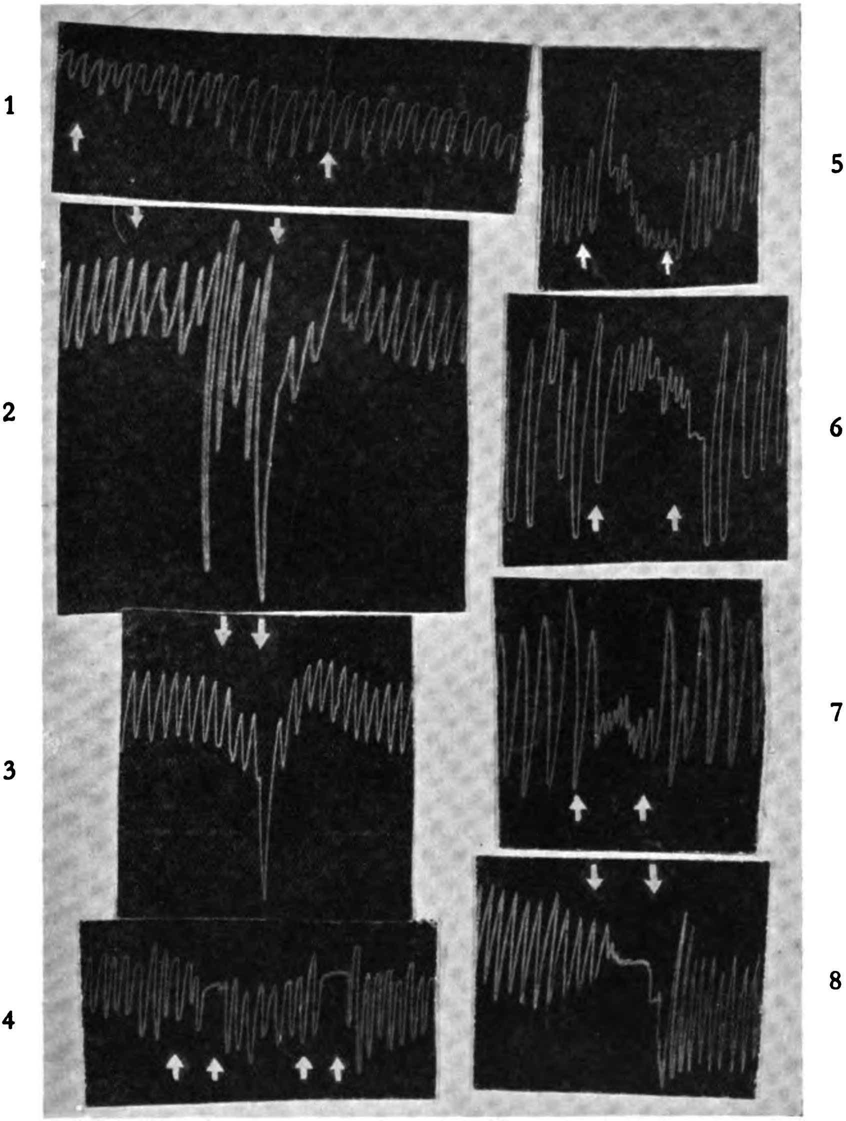


FIG. I. RECORDS OF TESTS.
The arc is screened between the arrows.

I append records (Fig. 1) taken from eight individuals, all members of the staff of the St. John Clinic and Institute of Physical Medicine :—

1. From a porter who has some chronic nasal catarrh and partial obstruction. The nose-clip was not used in this case. The breathing became more laboured while the arc was screened.
2. From a Sister who knew nothing about the object of the experiments. The nose-clip was used ; she had recourse to mouth breathing while the arc was screened.
3. From a similarly ignorant nurse who also opened her mouth to breathe when the arc was screened.
4. From one of the medical officers who suffers from chronic catarrh and partial obstruction. Nose-clip was not used. He could not breathe through his nose while the arc was screened.
5. From a nurse, ignorant of the object of the experiments ; she made rapid shallow breaths while the arc was screened. The nose-clip was used in her case
6. From a hall-boy who knew nothing about the experiments. He also made rapid shallow breaths through his nose while the arc was screened. The nose-clip was used.
7. A very experienced medical research worker, blindfolded and with the nose-clip on. His breathing became rapid and shallow while the arc was screened.
8. Myself, blindfolded and with the nose-clip on. Breathing through the nose was impossible while the arc was screened.

So little heat is given off by the tungsten arc, that the blindfold subject is quite unaware of its screening.

In the case of most subjects a glass screen, no less than an opaque one, cuts out the " nose-opening rays." The glass screen converts the sun and an arc into nose-closing sources.

Mr. Dufton unjustifiably assumes that the results confirmatory of mine, obtained by Dr. W. A. R. Thomson on sailors on H.M.S. *Excellent*, were due to suggestion. Dr. Thomson had carried out exact researches at Edinburgh University for four years, and knew well how to arrange his experiments so that suggestion was ruled out. Up to now he has tested 100 sailors, using the nose-clip, an electric heater, and an incandescent lamp as source of " nose-opening rays." He has obtained evidence of these rays in about 50 per cent. of the sailors. If he had used my new method, detailed above, he would, I believe, have obtained a considerably higher percentage of positive results.

There is no doubt of the existence of " nose-opening rays."

Apart from these, dark and dull sources of heat give-off less penetrating rays and produce skin sensations which are less pleasant than those produced by bright sources. The quality of the rays is an important matter.

BUILDING RESEARCH STATION, GARSTON, NR. WATFORD, HERTS.

THE EXCLUSION OF SOLAR HEAT

I.—LIGHT ROOFING STRUCTURES

By H. E. BECKETT, B.Sc.

IN this country it is not always realised that the problem of keeping a building cool in summer may in some cases be almost as important as that of warming the building in winter. Apart from any question of comfort, the generation of high temperatures in a building can often cause structural damage by the resulting expansive movements. Furthermore, where an air-conditioning equipment is installed, appreciable economies can be effected by excluding solar heat and thereby reducing the cooling load.

In the present article it is proposed to deal mainly with single-storey buildings of the " factory " type, in which the roofs—and sometimes the walls also—consist of light steel frames covered with sheets of galvanised-iron or asbestos-cement, alternating with large areas of glass. In such buildings, the chief problem is to keep the inside temperatures low enough in summer to enable men to perform heavy manual work in reasonable comfort : structural movements and the question of cooling loads are not usually of much significance.

Except where north-lighting is used, a large part of the heat gain is likely to occur through the roof-lights. Glass is very transparent to solar radiation, some commercial forms transmitting as high a proportion as 85 per cent., but it is almost completely opaque to the " low-temperature " radiation from bodies at ordinary room temperatures. A window or roof-light, therefore, acts as a heat valve, letting in the radiant heat easily but refusing exit to the radiation from the surfaces warmed by sunshine.

The only way of preventing this is to use some form of screen, light in colour to reflect the sun's radiation, but sufficiently translucent not to interfere too seriously with the natural lighting of the building. White blinds and the whitewashing of roof-lights are methods commonly adopted for this purpose.

The efficacies of various treatments have been tested at the Building Research Station in the following manner. Four large boxes, measuring 3 ft. 7 in. square by 1 ft. deep, were filled to within 4 in. of the top with slag-wool insulation, on which lay blackened copper sheets fitted with thermocouples for the recording of temperatures. The tops of the boxes were closed with sheets of ¼ in. rolled plate glass, measuring 3 ft. square. Conditions were thus somewhat similar to those within a building, the glass sheets representing roof-lights and the blackened copper sheets objects warmed by sunshine passing through the glass. A photograph of the boxes is shown in Fig. 1.

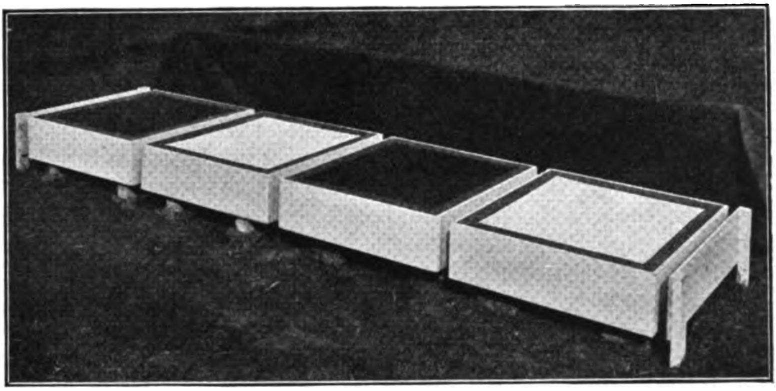


FIG. 1. BOXES USED FOR EXPERIMENTS ON THE EXCLUSION OF SOLAR HEAT

Continuous records of the temperatures within the boxes were obtained on a number of sunny days, with various modifications of the glass sheets. In order to associate the measurements made on different days, the amount by which the maximum temperature in a box exceeded the maximum air temperature for the day has in each case been expressed as a percentage of the corresponding excess beneath the clear glass. The resulting "relative temperature excesses," which enable the treatments to be placed in order of merit, are shown in Table I.

Of the treatments tested, the most effective proved to be two coats of whitewash on the outer surface of the glass, differences of temperature of more than 80° F. being observed beneath the glass treated in this way and beneath the clear glass. Subsidiary experiments have shown that whitewash with a suitable binder, such as tallow, will remain on a glass roof during the greater part of an English summer. Whitewash on the inner surface of the glass was appreciably less effective. Good results were also obtained with white calico blinds, but it is seldom practicable to instal blinds on

TABLE I.

THE EFFICACIES OF VARIOUS THIN STRUCTURES IN EXCLUDING SOLAR HEAT.

Structure	Surfaces Upper/lower	Relative Temperature Excess
Glass	Clear/clear	100
„	Clear/whitewash (1 coat)	61
„ white calico 1 in. below	Clear/clear	57
„	Green distemper (1 coat)/clear	55
„	Whitewash (1 coat)/clear	49
„	Clear/whitewash (2 coats)	46
„ white calico 1 in. above	Clear/clear	40
„	Whitewash (2 coats)/clear	28
Metal sheet	Black paint/black paint	42
„ „	Black paint/aluminium paint	36
2 metal sheets with 1 in. unventilated air-space	Black paint/black paint Black paint/black paint	33
Galvanised-iron, corrugations N.-S.	Untreated	29
Asbestos-cement—flat sheet	Untreated	24
2 metal sheets with 1 in. ventilated air-space	Black paint/black paint Black paint/black paint	23
Wallboard (½ in.) between metal sheets	Black paint//tinplate	19
Metal sheet	Tinplate/white paint	17
Wallboard (1 in.) between metal sheets	Black paint//tinplate	14
Metal sheet	White paint/aluminium paint	8
„ „	Tinplate/tinplate	6
„ „	White paint/tinplate	0
2 metal sheets with 1 in. unventilated air-space	White paint/tinplate Tinplate/tinplate	−1
2 metal sheets with 1 in. ventilated air-space	White paint/tinplate Tinplate/tinplate	−3

the outside of a roof-light, and it is not always possible to do so on the inside. A green distemper sold specially for greenhouses was inferior to whitewash.

On the opaque portions of a roof there is rather more choice in treatments for excluding solar heat. The most effective single treatment is again to whiten the outer surface of the roof and so to prevent the absorption of heat, but other possibilities are to incorporate some form of insulation in the roof and to take advantage of the non-radiating properties of polished metallic surfaces.

A number of measurements showing the relative effects of these various modifications have been made in the insulated boxes, and the results, expressed on the same basis as those for the glass specimens, are included in Table I.

It can be seen, for example, that a single tinplate sheet, whitewashed on top and untreated beneath, prevented the box temperature from rising above the maximum air temperature (relative temperature excess 0), whereas a similar sheet blackened on both sides gave a temperature excess 42 per cent. as great as that beneath the clear glass.

Less benefit was derived from placing 1 in. of wall-board beneath a blackened sheet than by simply whitening the upper surface of the sheet.

Again, aluminium paint is much less effective than tinplate as a non-radiating and heat-reflecting surface. This is doubtless due to the presence of the oil binder, for an aluminium-foil surface has been shown by numerous authorities to possess admirable properties in this respect.

The effect obtained with a closed air-space, with all four surfaces blackened, was surprisingly small, but considerable improvement was obtained when the space was opened to the air. An air-space with a white external surface and the other three surfaces metallic, showed only slight improvement over the single tinplate sheet whitened on top, but would have considerable advantages in reducing heat losses in winter, as previous experiments at the Building Research Station have demonstrated.*

It may be inferred from the above experiments that buildings of light construction can be successfully protected from the heating effect of sunshine by surface treatments alone, at a comparatively low cost and without adding to the weight of the roof.

---

* *Journal I.H.V.E.*, 1933, vol. 1, p. 263.

INSTITUTION OF HEATING AND VENTILATING ENGINEERS

REPORT

SESSIONAL MEETING, DECEMBER 5th, 1934

A Sessional Meeting of the Institution was held in the Lecture Theatre of the London School of Hygiene and Tropical Medicine, Keppel Street, London, W.C.1, on December 5th, 1934 ; Mr. C. R. Allensby, Vice-President Elect, occupied the Chair at the commencement of the meeting, owing to the fact that the President, Mr. R. C. Ching, had been detained at another meeting ; the President attended later, and Mr. Allensby vacated the Chair in his favour.

There were about sixty present ; the following signed the attendance register :—Messrs. F. F. Powell, H. Leslie Egerton, C. R. Allensby, L. J. Fowler, J. H. Bernard, J. G. Ford, G. L. Copping, J. N. Bottrill, L. A. Baines, H. Fitch, W. Ferne, F. M. H. Taylor, J. Selley, E. B. Darby, A. W. Beaven, S. B. Chandler, A. J. Bullivant, Louis A. Forni, F. C. Michell, H. N. Blake, L. Copeland Watts, B. A. Pountney, G. Nelson Haden, J. H. Bryant, A. St. Leger, R. Ballan, H. M. Vernon, H. F. W. Joyce, Alcwyn A. Jones, A. Fleming Browne, J. C. Byles, R. Grierson, F. S. Reed, T. E. Barnes, S. Adams, H. E. F. Heath, R. C. Ching, T. H. P. Hatchett, J. H. Francis, G. R. Jackson, T. G. Noble, L. W. Andrew, T. F. C. Potterton, A. Hunt, C. S. K. Benham, and H. B. Watt (Secretary) (London) ; L. Broadbridge (Brighton) ; A. Ord (Croydon) ; A. T. Lambert (Chingford) ; J. W. Cowan (Aldershot) ; and visitors :—L. C. Mount, J. Wainwright, W. Jennon, F. J. Laws, W. Hesling, L. C. C. Rayner, Miss H. Day, W. Boon, T. Gilchrist, C. F. Kingham, W. Martin, F. A. Mullitt (London) ; A. F. Dufton (Garston) ; R. G. Brocken (Worcester Park) ; W. P. Andrews (Harrow) ; A. R. Redbourn (Brighton).

Mr. C. R. Allensby, in opening the meeting, explained the absence of the President at the beginning and introduced Mr. L. J. Fowler.

Mr. L. J. Fowler, B.A., A.M.I.C.E. (Member), then read his paper on " Manufactured Solid Fuels for Heating."

MANUFACTURED SOLID FUEL FOR HEATING

By L. J. FOWLER, B.A., A.M.I.C.E. (Member)

SESSIONAL MEETING, LONDON, DECEMBER 5th, 1934

Conservative estimates indicate that the coal at present known to exist in the United Kingdom will, at to-day's rate of output, last for four or five centuries. This period may be increased by the discovery of new coal-fields or of means for using the low quality and small coals which are now wasted to a considerable extent. Except, therefore, for the far-seeing altruist there appears to be no immediate concern as to the exhaustion of supplies, but it must be borne in mind that as time goes on mines will become deeper and thus more difficult and more costly to work.

It is, however, becoming more and more appreciated that the comparatively limitless supply of coal available does not justify the uneconomical methods of usage so prevalent at the moment. The annual coal consumption in the United Kingdom is approximately as follows :—

1. In the raw state—147 million tons.
2. Carbonised by the gas industry—18 million tons.
3. Carbonised by the coke-oven industry—19 million tons.

Total—184 million tons.

Of the 147 million tons consumed in the raw state, approximately 35 million are burnt in domestic grates.

The above figures show that only one-fifth of the coal used is subjected to preliminary treatment by carbonisation which, in addition to giving smokeless solid and gaseous fuels, enables valuable by-products such as tar, benzole and ammonia to be abstracted, as well as light spirits for use as fuels in internal-combustion engines.

One of the greatest objections to the consumption of coal in the raw state is the resulting atmospheric pollution, it being estimated that annually some 3 million tons of potential fuel, as soot, escape into the atmosphere from industrial and domestic chimneys. Comparison is only needed of the obscured winter skies in London and the clear blue winter skies of New York to judge the accumulated effect of numberless smoking chimneys. Pre-treatment of coal is essential to its rational use, and there is no doubt that annually a larger and larger percentage of the total coal used will be treated.

The production of motor spirit and fuel oil from coal by hydrogenation is reported to have reached the commercial stage. In the recent Melchett Lecture of the Institute of Fuel, Dr. Bergius, the eminent German chemist, stated that his own company was putting down a plant which would produce 150,000 tons of petrol a year from coal, and would employ more than 12,000 men; and it is anticipated that the new Billingham hydrogenation plant will use 350,000 tons of coal.

The Carbonisation of Coal.

The carbonisation of coal consists essentially of heating it in retorts from which air is excluded, and collecting and separating the products resulting from the operation. The products are as follows :—

1. *Gases.*—Parts of these are condensable, and from the remainder may be obtained other products—benzole, ammonia, etc. The cooled and washed gases are used as illuminants or heat or power producers.
2. *Liquids.*—These are produced in a complex mixture known as "tar," which on distillation yields a number of products, some liquid and some solid.
3. *Solids.*—Known as coke or semi-coke, consisting mainly of carbon, the former containing 0.5 to 2 per cent. of volatile matter, and the latter 8 to 12 per cent.

The proportions of the products obtained, and their chemical and physical nature vary according to :—

1. The coal or mixture of coals used.
2. Temperature of carbonisation.
3. The method and period of heating.

High-temperature Carbonisation.

This is carried out at temperatures between 1,200° to 1,350° C. and is undertaken by two industries :—

(*a*) The gas industry, which carbonises approximately 18 million tons of coal per year, with the primary object of producing gas—coke being the chief by-product.

(*b*) The coke-oven industry, which carbonises approximately 19 million tons a year, with the primary object of producing a hard coke suitable for the metallurgical industry.

In the manufacture of gas the coal is carbonised in one of two types of retort—horizontal or vertical. Horizontal retorts usually have capacities of 12 to 15 cwts., the process of manufacture is intermittent, and the coke obtained is comparatively dense. Vertical retorts or chambers which give a larger output per unit of ground area, can either be worked intermittently or continuously, and give a lighter coke.

In the coke-oven industry coal is carbonised in vertical retorts at temperatures comparable to those normal in gas manufacture, but for longer periods. The coke obtained is very hard and contains slightly less volatiles than gas-coke.

Table I gives the densities of high-temperature coke obtained by the above methods.

TABLE I.[1]

Class of Coke	Weight of Coke above 2 in. on a dry basis in lb. per cu. ft.
Continuous vertical retort	18 to 22
Intermittent vertical chamber	26
Horizontal retort	26
Coke oven	27

In each case the properties of the coke are affected by the types of coal carbonised, and it is the modern practice in both the gas and the coke-oven industries to blend the coals to ensure the production of a good type of coke. Reference is made later to blending.

In Table II figures are given which show the products obtained from the carbonisation of typical coals in continuous and intermittent vertical retorts in gas-works, and Table III gives their values.

TABLE II.[2]

PRODUCTS OF CARBONISATION OF TYPICAL COAL IN GAS MANUFACTURE.

	Continuous Vertical Retorts	Intermittent Vertical Retorts
Calorific value of gas in B.T.U. per cubic foot	500	500
Therms per ton	80	82
Tar, gallons per ton	12	10
Dry fuel, percentage on cwt. of coal	13.75	14.5
Gross coke with 5 per cent. water (percentage of wt. of coal) ..	69	69

TABLE III.[2]

COSTS OF CARBONISATION AND OF PRODUCTS OF TYPICAL COAL IN GAS MANUFACTURE.

(All figures pence per therm)

	Continuous Vertical Retorts	Intermittent Vertical Retorts
Coal cost	3.300	3.220
Labour	0.129	0.110
Fuel	0.395	0.413
Capital	0.374	0.435
Total	4.198	4.178
Less :		
Gross coke	1.889	1.868
Tar	0.375	0.305
Surplus steam	0.246	0.076
Total credit	2.510	2.249
Net cost of gas per therm ..	1.688	1.929

The above figures of cost are interesting to the heating engineer, since they give an indication of the basic price of gas. To the figures shown all distribution and selling charges must be added before the price to the consumer can be assessed. As a comparison it is interesting to state that the cost of an electrical unit at a power station is approximately 0.2d. per kilowatt hour, i.e. approximately 6d. per therm (100,000 B.T.U.).

The figures in Table III also indicate clearly how dependent is the price of gas upon the price of coke. A fall in price of 1s. per ton in the cost of coke being equivalent to a rise of 0.15d. per therm in the price of gas.

Table IV gives typical analyses of gas- and furnace-coke :—

TABLE IV.

	Gas-coke per cent.	Furnace-coke per cent.
Fixed carbon	88.21	89.66
Volatile matter	1.28	0.71
Ash	7.54	7.08
Sulphur	0.90	0.91
Moisture	2.07	1.64

The main object of the gas and coke-oven industries is to get the maximum yield of gas or coke, or both ; hence the use of high temperatures and the low volatile content of the coke obtained.

The tar produced during high-temperature carbonisation of coal consists of a complex mixture of compounds, some of the more important being light oils (benzene, toluene) tar acids (creosote), napthalene, anthracene, etc., which are produced by the action of the great heat on the simpler compounds first distilled. Benzole and similar compounds are obtained from the gas ; and from the tar, phenols, cresols and ammonia are manufactured.

Low-temperature Carbonisation.

Carbonisation at low temperatures—450° to 700° C. results in a greater proportion of the volatile matter of the original coal being left in the coke, which is thus more reactive. In Table V are given the quantities of gas, tar and solid residue, resulting from the carbonisation at both high- and low-temperatures of one ton of a typical coal, containing 33 to 34 per cent. of volatile matter, 58 to 59 per cent. of fixed carbon, and 6 per cent. of ash.

TABLE V.[8]

	High-temperature	Low-temperature
Gas cubic feet ..	11,000-14,000	3,500-4,000
Tar gallons ..	10	20 to 22
Solid residue cwt.	14	15

The gas obtained during low-temperature carbonisation has a higher calorific value than that at high temperature, but the quantity is usually less than one-half, and although large sums have been spent on research, low-temperature carbonisation has so far not proved generally acceptable to the gas-making industry.

There are many eminent men, however, who believe in the future of low-temperature carbonisation, and brief reference is therefore made to the uses affecting the heating industry, of the solid residue, known as semi-coke, obtained for this process.

Semi-coke is more friable and less porous than high-temperature coke, and ignites readily. Its main commercial outlets for heating are as follows :—

(1) *As a Domestic Fuel.*—An immediate outlet for semi-coke lies in the domestic-fuel market, for in spite of the extended use of central heating in domestic buildings, the open fire is an intrinsic part of the British home, and its popularity will fade slowly. In justification of this statement reference might be made to a modern tendency in central-heating practice for the large blocks of flats which are becoming so numerous, which indicates that even in this type of building the use of open fires will continue. Central-heating apparatus is now frequently installed to give not more than a 25° difference in temperature between the building itself and the outside air. During a large part of the winter it is necessary, therefore,

to supplement the heating, and the open grate burning smokeless fuel, with gas ignition, offers a convenient and cheap method. Incidentally, the practice of installing a heating installation of this type is sound economically, for an equipment capable of giving a 35° F. rise will only operate on full load during perhaps two weeks of the winter, and for the remainder of the year full return is not obtained for the capital invested.

Semi-coke is an excellent domestic smokeless fuel, clean, convenient and easy to ignite—a popular example is Metro-Coalite.

(2) *In Gas and Coke Oven Industries.*—A further important use is offered by the improvement in high-temperature coke, either gas or furnace, which is obtained when semi-coke is blended with coals which do not in themselves produce a good type of coke (see paragraph *re* Blending).

(3) *As a Boiler Fuel.*—Semi-coke can be pulverised ; it is quite dry and in the pulverised state flows with ease. The percentage of heat emitted as radiation is high, and it has many attractions as a boiler fuel.

Effect of Temperature of Carbonisation on Coke Properties.

There is close connection between carbonisation temperature, and the volatile content and ignition temperature of the coke or semi-coke obtained.

Table VI gives the results of actual tests.

TABLE VI.[4]

EFFECT OF CARBONISING TEMPERATURE ON PROPERTIES OF COKE OBTAINED FROM A TYPICAL COAL.

Temperature of carbonisation °C	Volatile matter	Combustibility	Apparent density	True density	% porosity	*Ignition temperature* 20-30 mesh °C	*Ignition temperature* 180 mesh °C
500	10.8	19.8	0.606	1.36	55.3	455	401
550	11.0	18.0	0.609	1.35	54.8	453	419
600	7.6	18.0	0.663	1.44	54.0	471	432
620	8.7	17.4	—	—	—	475	—
650	.8	20.4	0.664	1.46	54.5	470	438
665	8.1	18.0	0.630	1.40	55.0	466	439
700	6.0	8.6	0.780	—	—	503	—
720	4.7	6.9	0.769	1.66	53.7	519	488
750	5.8	8.3	0.752	1.62	53.6	516	490
800	2.7	6.2	0.808	1.72	53.0	574	545
850	2.0	5.7	0.819	1.71	52.1	579	546
900	2.9	5.3	0.873	—	—	577	—
1050	0.8	4.6	—	1.79	—	626	563

Coke exhibits a marked change in characteristics as the carbonisation temperature passes 700° C., there being a sharp fall in combustibility, an increase in ignition temperature, and an increase in density. This temperature can be looked upon as the critical temperature between low- and high-carbonisation. Coke produced below 700° C. is black, and as the temperature rises, the characteristic silvery sheen becomes apparent. The porosity remains substantially unchanged.

It is popularly supposed that combustibility increases with porosity which is visible to the naked eye. This is not true without qualification, for it is the fineness of cellular structure of the coke which is much more important. Low-temperature coke has a structure of fine and highly reactive cells free from graphitic carbon.

At high temperatures the surface of coke becomes coated with a layer of graphitic carbon, which definitely reduces combustibility.

The Behaviour of Coke in Heating and Domestic Hot-water Boilers.

Coke is the fuel most widely used in heating and domestic boilers, but few of its users have intimate knowledge of the influence on combustion with variations in its physical and chemical properties. Reference is made below to the main factors controlling combustion, and figures are quoted from recent tests.

Rate of Combustion.—The rate of combustion is a function of the rate of oxygen supply, which is controlled by :—

(1) The conditions of operation (flue, damper opening, etc.).
(2) Thickness of fire.
(3) Condition of coke.

Item 1.—With coke no abnormal draught conditions are necessary.

Item 2.—The thickness of fire—is important. If the fire is too thin, excess air is admitted to the boiler in considerable quantities, and blow-holes may occur in the fire-bed. The lowering of combustion efficiency due to excess air is given in Table VII.

TABLE VII.

Carbon dioxide per cent.	Excess Air per cent.	Fuel loss per cent.
5	262	37
6	202	30
7	159	25
8	127	22
9	102	20
10	82	18
11	66	16
12	52	15
13	40	14
14	30	13

If the fire is too thick the carbon dioxide formed in the lower layers of the fire is reduced to carbon monoxide in the upper layers—an endothermic action which has a cooling effect on the fire.

A suitable thickness of fire is 6 to 10 in., depending on the grade of coke used. The chief reason for the high combustion efficiency of gravity-feed coke-fired boilers is that they maintain their operation with a fire-bed of constant thickness.

Consideration of fire-bed thickness introduces the question of boiler ratings. Both in large and in small hand-fired boilers better efficiencies are obtained when boilers are of ample size for their duty. With boilers of ample size stoking can be carried out at comparatively infrequent intervals, without extreme variations in depth of fire-bed, the deleterious effect of which has already been mentioned. Furthermore, at a low rate of combustion per square foot of grate area, clinker formation is less, so that cleaning of the fire is only necessary after long periods, and thus minimises losses due to :—

(*a*) Unconsumed fuel being removed with the clinker.

(*b*) Cooling effect due to cold air passing through the boiler during cleaning periods.

Results of tests of a boiler at different rates of firing are given in Table VIII.

TABLE VIII.[4]

THE EFFECT OF TYPE OF FUEL AND RATE OF COMBUSTION ON EFFICIENCY,

Tests on Small Domestic Boiler					
	Proximate analysis of fuels			Rate of fuel combustion lb./hour	Efficiency per cent.
	Moisture per cent.	Volatile matter therms/ton	Ash per cent.		
High-temperature coke	3.7	2.2	9.30	1.2	71
				1.77	68
				3.39	60
				4.27	57
Low-temperature coke	3.1	13.76	3.1	1.72	61
				2.14	57
				2.19	56
				4.29	53
				4.56	51
Semi-anthracitic Scotch coal	0.4	11.71	6.55	1.61	53
				1.94	56
				4.08	54

The rate of combustion is restricted by the presence of ash or by poor grading of the coke, and as indicated later, steps are now taken in the manufacture of gas-coke to control these factors.

Moisture Content.—Both laboratory tests and experience have shown conclusively that in spite of popular belief no improvement in combustibility is obtained by the presence of water in coke. If coke is quite dry, it is inclined to be dusty, and the most desirable water percentage is probably 3 per cent.

Behaviour under Slow Firing Conditions.—Failure to maintain a coke-fire in water boilers can be due to one or other of two causes—either the rate of combustion is so low that the heat loss through water-cooled walls of the combustion chamber causes the fuel to fall below its ignition temperature, or the rate of combustion may be maintained so high that the fuel is consumed before the fire again receives attention. Between these two limits lies a range of conditions which the boiler attendant must maintain by mean of dampers, and regulation of air supply. To the property of the fuel which determines the width of this range, the term " flexibility " is given.

The Effect of Grading of Coke.—Table IX shows the result of tests on the flexibility carried out on a boiler which was fired with six different grades of the same coke, containing 2.6 volatile therms per ton, i.e. the calorific value of the volatile matter contained in a ton of fuel was 260,000 B.T.U.

TABLE IX[4]

THE EFFECT OF SIZE OF COKE ON FLEXIBILITY.

Grade inch	Flexibility	Minimum damper opening for 8½ hours combustion. ⅛ in.	Max. period of combustion. Hours
2—1	Nil	—	8
1½—1	Nil	—	8
1—⅝	1—2	5	9
¾—½	2	4	11
⅝—⅜	4	3	16
½—¼	7	3	24

The effect of the size of the coke is very marked, smaller fuels giving greater flexibility than larger. It is not possible to take full advantage of the increased flexibility of the smallest grades of fuel, since difficulties then arise through fuel falling through the fire-bars, and through excessive clinker formation.

Table X shows the result of a second series of tests, made to determine the effect of maintaining the same average size of particle, but altering the limits through which the size is allowed to vary. There is no change in the flexibility.

TABLE X[4]

THE EFFECT OF CLOSENESS OF GRADE ON FLEXIBILITY.

Grade inch	Flexibility	Minimum damper opening for 8½ hours' combustion. $\frac{1}{8}$ in.
1—$\frac{3}{8}$	1	5
$\frac{3}{4}$—$\frac{5}{8}$	1	5

The Effect of Volatile Matter.—Tables XI and XII show that the percentage of volatiles in coke has a big effect on the lighting and pick-up time, and the flexibility respectively. Tests A and B in Table XI were carried out with different boilers, and the results are not directly comparable.

TABLE XI[4]

RELATIONSHIP BETWEEN EASE OF IGNITION AND LIGHTING TIME.

Coal	Coke No.	Volatile matter therms/ton	Pick-up time min.	Lighting time min.
A	1	4.3	78	12.5
	2	2.2	110	25.0
	3	1.3	114	25.0
	4	0.9	156	50.0
B	5	4.8	84	9.0
	6	1.2	94	14.0
	7	0.7	102	26.0
	8	0.6	117	25.0

TABLE XII[4]

THE EFFECT OF VOLATILE MATTER CONTENT ON FLEXIBILITY.

Volatile matter therms/ton	Flexibility
1.7	2
2.4	3
3.0	4
3.5	5
4.1	6

Table XIII is interesting in that it shows the reduction in lighting time by the addition of small amounts of semi-coke.

TABLE XIII[4]

UNEVEN DISTRIBUTION OF VOLATILE MATTER.

Mixture	Volatile content of mixture therms/ton	Lighting time min.
High-temperature coke	2.6	25
High-temperature coke + 5 per cent. low-temperature fuel ..	3.9	15
High-temperature coke + 10 per cent. low-temperature fuel ..	5.5	8

Clinker.—Clinker is formed by the fusion of ash, and occurs primarily in the centre of the fire, where the temperatures are highest.

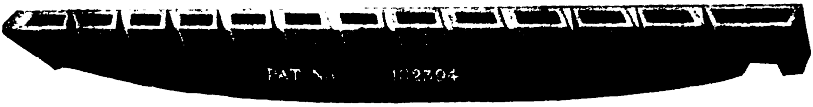


FIG. 1. THE ECONOMIC FIREBAR.

Other things being equal, it is found that the larger the grade of coke the less is the trouble experienced through clinker. (See Table XIV.)

By provision of means to keep firebars cool it is possible to increase the rate of combustion of gas-coke to a figure as high as 30 lb. per hour per sq. ft. of grate area. The air spaces between the firebars must be ample—about 50 per cent. of the gross area is advisable—and there are a number of bars on the market, especially designed with this in view. The bar illustrated in Fig. 1 is provided with diagonal slits which give additional air space, and in each of the diamond-shaped sectors a pocket is formed which fills with ash and prevents the adhesion of clinker to the bars.

Additional cooling is obtained by provision of steam or water sprays in the ash-pit, a remarkable increase in combustion rate per sq. ft. of grate area being obtainable by this means.

A third means of reducing clinker trouble, is to shovel a bed of lump chalk onto the firebars before recharging the fire after cleaning. The fire is made on the chalk, and the clinker fuses to the chalk, not the firebars, and is readily removed with the slice.

Ash.—Since clinker is formed by the fusion and subsequent solidification of ash, it has been assumed that clinker formation is closely related to the fusion temperature of the ash. Experience of the operation of coke-fires at high rates of combustion, indicates that this is not so, and that clinker formation can be controlled more effectively by care in operation rather than by change in the ash characteristics of the coke used.

Shale.—The presence of shale adds considerably to the formation of clinker. The ash when fused, wets the surface of the pieces of shale, and cements them together to form a solid clinker. Steps are, therefore, taken in the preparation of gas-coke to remove shale.

Size of Fuel.—With the use of the smaller grades of coke, the tendency to form clinker is enhanced. Experiments have shown that coke ¼ to 1¾ in. grade can be burnt at a rate as high as 6.3 lb. per sq. ft. of grate area per hour before clinker formation is observed, but that clinker formation commenced at 4.4 lb. per sq. ft. per hour with coke graded between ½ and ¾ in. The use of large coke as a means of avoiding clinker is, in practice, restricted by the fact which has already been pointed out (Table IX) that large coke reduces flexibility under slow-fire conditions.

TABLE XIV[4]

SIZE OF FUEL AND CLINKER FORMATION.

Size of Fuel	Damper opening in.	Rate of combustion lb./hour	Ash formed lb.	Clinker formed lb.
100 per cent. ⅝—1 in.	½	1.03	1.3	Nil
20 per cent. ⅝—1 „ 60 per cent. ¼—⅝ „ 20 per cent. 0—¼ „	½	0.9	1.5	0.6
100 per cent. ⅝—1 in.	¾	1.4	1.4	Nil
20 per cent. ⅝—1 „ 60 per cent. ¼—⅝ „ 20 per cent. 0—¼ „	¾	1.0	1.3	0.8

The Comparative Efficiencies of Various Fuels in a Domestic Boiler.

The figures given in Table VIII above indicate that high-temperature coke is more efficient than fuels of higher volatile content. This is to be expected, as the latter fuels burn with more flame and give a higher flue-gas temperature.

The test also shows that higher rates of combustion give a lower efficiency.

The Properties Desirable for Coke for Heating and Domestic Boilers.

Reviewing briefly the tests referred to above :—

(1) The most important feature for satisfactory operation is flexibility, i.e., ability to burn for long periods without attention. Flexibility is determined by bulk density—the number of pounds of fuel which can be charged onto the fire—and by the minimum

rate of combustion. The latter is chiefly dependent on the volatile content, a minimum figure for this being 2½ therms per ton, but is also dependent on the size of coke, smaller grades having greater flexibility than larger.

(2) Large ash content reduces the rate of combustion.

(3) The size of coke and the presence of shale are the main factors affecting clinker formation, the fusion temperature of the ash being unimportant.

(4) Clinker troubles can generally be obviated by cooling the firebars.

A boiler of ample capacity running at low load requires less attention and gives higher efficiences than a smaller boiler run at high load.

The Blending of Coals in the Gas Industry.

Experimental work has been carried out for almost a century in connection with the blending of coals for carbonisation. This research has two objects :—

(1) To produce a blend which during carbonisation will have a maximum thermal conductivity, and thus will be carbonised more rapidly and enable the output of the plant to be increased.

(2) To improve the quality of the coke by blending a non-caking coal or coke breeze with caking coals. Improvements are obtained in respect of the ease of combustibility, or strength, or density of the coke, or several of these properties simultaneously.

During the last few years one London gas company has expended over £100,000 on experimental work and the installation of blending apparatus.

In coke-ovens the coals are finely crushed before carbonisation, and blending is comparatively simple, and has been a standard practice for some time. Owing to the crushing the ash is disseminated evenly throughout the coke, but has no serious effect on its use in metallurgical and industrial processes.

In the gas industry, however, crushing of the coal retards the evolution of gas and disseminates the ash throughout the coke in a way that is undesirable for the domestic and small-boiler market. Intimate blending thus becomes a more difficult matter and has brought about the necessity for the research work and the extensive plant referred to above.

An interesting development is the use of semi-coke in blending. In London it is difficult to obtain, at attractive prices, non-caking coals in the quantities required—the cheap slacks having, generally speaking, too high an ash content for coke manufacture. It has been found, however, that if selected non-caking coals are carbonised at low temperatures, and the semi-coke is then blended with the caking coal, good coke can be manufactured at a considerably lower non-caking to caking coal ratio. A large plant is at present in operation in London, using semi-coke regularly for this purpose.

Preparation and Cleaning of Coke for the Market.

The Technical Committee of the London and Counties Coke Association has arranged a standard form of grading coke. The standard grades are set out in Table XV.

TABLE XV.

Name	No.	Sizes inches	Uses
Large or unbroken	1	Over 2	No. 1. Very large central-heating boilers. Steam raising
Broken	2	Within the limits of 1—2	No. 2. Large central-heating boilers. Open fires
Coke boiler nuts	3	½—1½	No. 3. Small central-heating boilers. Large domestic hot-water-service boilers
Forge beans	4	⅜—¾	No. 4. Small domestic hot-water-service boilers. Closed stoves. Kitchen ranges. Mechanical Stokers

The variation of density of different types of coke obtained from coke-ovens, intermittent vertical chambers, horizontal retorts and continuous vertical retorts, has been indicated earlier (see Table I). The correct type of coke can now be produced and supplied to meet any reasonable requirement. For instance, the large coke made in continuous vertical retorts, weighing 18 to 22 lb. per cu. ft., when cut to a suitable size will burn cleanly in open grates, and the heavier cokes will meet heavy industrial loads.

The growth in popularity of the small domestic boiler has opened up a market for a comparatively reactive coke. It is found that cutting increases reactivity—probably owing to the increase in the surface area to volume ratio caused by sharpness of fracture, and coke is, therefore, nowadays specially cut in order to make it more suitable for certain markets. This not only means the introduction of an extra process, but in cutting, considerable quantities of breeze are formed, the value of which is low compared to that of large grade coke, and it is therefore necessary to charge slightly more for cut coke. In some gas-works it is the practice to screen the coke, in order to remove all pieces less than 1½ in. in size, which contain a comparatively high percentage of ash, and to use the smalls solely as fuel in the gas-works themselves. The coke which does not pass through the screen is then graded and cut, or both, according to the requirements of the market.

During the last three years the gas companies which are members of the London and Counties Coke Association have spent over £1,500,000 on apparatus for improving the quality of coke.

The coal used in the coke-oven industry is crushed to particles not exceeding ⅛ in. in size, and the shale content then removed before carbonisation, so that furnace-coke is practically free from shale. On the other hand coke produced in gas manufacture contains 1½ to 2 per cent. of free shale, since the coal, before carbonisation, is not crushed below 1½ in. Previous reference has been made to the way in which shale assists the formation of clinker. Its elimination is also essential owing to the popularity of small boilers, the small grate areas of which can be rapidly choked by this material, which will not pass through the firebars. In the past the method of extracting the shale has been to wash the graded coke, but the practice of stocking the coke direct from the screens and washers in hoppers from which lorries are fed directly, does not always allow sufficient time for the water absorbed during washing to drain away, with the result that there is a risk that coke may sometimes be delivered wet to the consumer. It has, therefore, sometimes been found necessary to remove the washed coke from the hoppers, and to store it in heaps for two weeks to allow the moisture to drain away, a treatment which entails considerable cost. Dry cleaners have consequently been developed, and are being installed in a number of gas-works. The coke is delivered on to a cleaning deck made of perforated plate which reciprocates at high speed, air under a small pressure is forced through the perforations, and the coke floats from one end of the deck to the other, and in doing so the heavy shale falls to the level of the deck, where it is worked to the one side by diagonal riffle strips, the clean coke being discharged at the other side. The wear and tear is less with this system than with water cleaning, and the finished product is much superior.

The coke after classification and grading is stored in hoppers, and surplus coke is deposited in heaps, usually in an unscreened condition. During storage in hoppers, the graded coke suffers from segregation and abrasion, and it is necessary to re-screen to remove under-sized coke before delivery to customers. A considerable proportion of coke for heating is delivered in hundredweight sacks, and a vibrating screen is used to remove breeze from the coke as it passes from the hoppers into the sacks. The weighing is carried out with the greatest accuracy, and Council Inspectors have the power to stop lorries and to check up the weights of the sacks.

Manufactured Solid Fuels for Open Fires.

The combustion of gas-coke in open fires is now practised extensively, and over 60,000 special grates were installed last winter in the greater London area. Just after the War this question was considered very carefully, but at that time three difficulties had to be faced :—

(1) The percentage of ash in the coke was frequently as high as 15 per cent., and resulted in a dirty fire which was deficient in radiating power and gave no cheerful glow.

(2) Unsuitable quenching of the coke as it was abstracted from the retorts resulted sometimes in as much as 10-15 per cent. of moisture being present.

(3) The coke was difficult to ignite.

As far as ash was concerned, the gas companies were not entirely to blame, since at that time trade was good, and the collieries saw no reason why they should lay down plant to remove dirt and shale when it could be sold at the same price as good coal, and it was not until prices fell, in the middle of the last decade, that competition became keener, and the condition of the coal was improved at the collieries. The actual deliveries of coal to the gas-works became cleaner and, in addition, as explained above, in the gas-works themselves further steps were taken to remove shale from the coke. In the same way gas companies introduced new methods of quenching and washing, with the resulting low moisture content of coke as delivered. In spite of these improvements the difficulty of ignition still remained, and with the ordinary firegrate was always serious. Furthermore, unless the fire was designed to hold a deep fire-bed, and the back and sides were well-insulated, a bright fire could not be maintained, and recovery after the addition of fresh fuel was slow. This problem was open to attack by two methods :—

(1) By development of a suitable low-temperature fuel.

(2) By a modification of the domestic grate to render it suitable for the combustion of high-temperature coke.

Both methods of approach were investigated, and in spite of the sums expended on low-temperature carbonisation, development on an economic basis has been slow. Research on the grates themselves was lengthy, but comparatively simple, and appliances are now available which are giving excellent results and becoming daily more popular. Fig. 2 shows a section through one of the many successful coke-burning grates now on the market.

If a fuel of low combustibility is to be maintained successfully in actual combustion, care must be taken to prevent the temperature falling below the ignition temperature. If the volume of fuel in a grate is small, radiation from the outer pieces being unimpeded will cause their temperature to fall and will cause them to become non-luminous unless it is counteracted by heat obtained from the centre of the fire. It is, therefore, essential in coke fires to have a deep fuel-bed. Furthermore the coke adjacent to the sides and back of the fire will become non-luminous unless its temperature is kept high by the use of satisfactory insulating material at the sides and back of the grate.

With these two requirements, coke will burn satisfactorily for a while, but unless the ash produced on combustion is easily removed, it will choke the air spaces and the fire will die down. It is, therefore, necessary to have narrow firebars widely spaced, through which the ash will fall. The firebars are generally sloped so that as the fire burns there is a sliding motion down the bars, which disturbs the ash and causes it to fall between them.

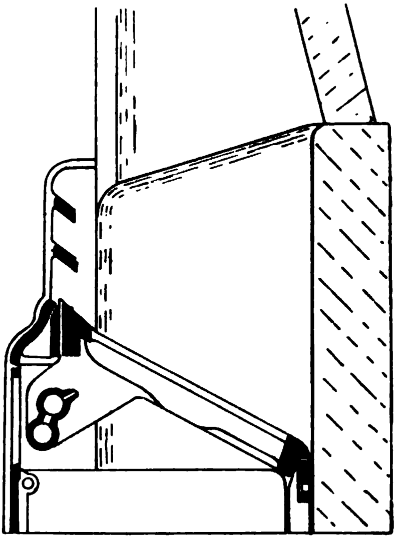


FIG. 2. TYPICAL OPEN COKE GRATE.

The ignition difficulty has been overcome by the incorporation of a gas-burner beneath the front of the grate, arranged so that the jets cannot be choked by falling ash. The gas-flames must project into the coke and the kinetic energy of the gas must not be reduced too much by the introduction of primary air.

Properties Desirable in Coke for Use in Open Fires.

Summarising research work on this subject, it is found that :—

(1) Moisture content of approximately 3 per cent. is most suitable for coke to be burnt in open fires, for this content tends to prevent coke appearing dusty during handling.

(2) For reasonably easy ignition the volatile therm should be about 2.6 per ton, but once ignited the therm content

has little effect on the behaviour of the fire, the figure of combustion being controlled by the ash content.

(3) The volume of the ash has a bigger effect on radiation than its weight, and it has been found that the smaller the coal is ground before carbonising, the larger is the ash volume.

(4) The most satisfactory grade of coke for use in open fires is broken coke 1 to 2 in. in size.

Summarising the paper, there are a number of types and grades of coke, each suitable for a specific purpose. When purchasing, therefore, the supplier should be informed of the use to be made of his products. The highest satisfaction can only be obtained when the right kind of coke is burned in the right way.

In conclusion, the writer wishes to express thanks to Mr. W. L. Boon and Dr. F. J. Eaton for their assistance in the preparation of this paper.

He is also greatly indebted to the South Metropolitan Gas Company for permission to so liberally abstract from their recent publication entitled *The Solid Products of the Carbonisation of Coal*, which gives details of the extensive and valuable work carried out by the Company's Research Engineers on the combustion of coke and semi-coke in boilers and open fires.

References.

[1] F. M. Birks, O.B.E., M.I.M.E., etc., of the Gas Light & Coke Co., in a paper before the *American Gas Association*, 1933, entitled : "The Preparation of Coke for the London Market."

[2] R. B. Richards, M.I.C.E., M.I.M.E., etc., in a paper before the *Eastern Counties Gas Managers' Association*, October, 1934.

[3] A. T. De Mouilpied, M.Sc., Ph.D., etc., in a paper before the *Electrical Power Engineers' Association*. (Technical Series No. 7.)

[4] From "The Solid Products of the Carbonisation of Coal," published by the South Metropolitan Gas Company, 1934.

DISCUSSION.

The President (Mr. R. C. Ching) remarked that the paper was one of very great interest to all the members of the Institution. Personally, he had been rather disappointed to see that other fuels and other methods of firing were not dealt with in it, but it was essentially a specialist paper on manufactured solid fuel. It was very surprising to see from it the enormous amount of research and experimental work which had been carried out almost entirely by the coal and coke companies in order to improve their methods of production, and in order to enable them to put before the heating engineer various grades of fuel suitable for particular purposes. At one time, those engaged in the heating industry used to buy coke without paying very much attention to the details of it as set out in

Mr. Fowler's paper ; and he thought the gas companies, by their manufacture and by their research work, had done a very great amount of good to the heating industry in being able to produce a fuel—and a graded fuel—which would suit the particular purpose for which the heating engineer required it.

Dr. F. M. H. Taylor congratulated the author on his complete grasp of what might be called the economics of manufactured fuel. The way in which Mr. Fowler had set out the manufacturing costs of the various products derived from coal, namely, gas, coke and electricity, was really masterly, and it would certainly add to the interest which the heating industry already took in the fuels used in the plants which they installed.

He had been particularly interested to see the author's reference to smoke and soot in referring to raw coal, because it was the hope of most of those engaged in the heating industry that the advent of central heating and smokeless fuels would soon banish smoke and soot.

He might add that there was one feature about the open fire which would make it go out of use very slowly, if at all, and that was the comforting effect of radiant heat on the human body. It had been shown quite definitely that a stimulating effect was obtained by the warming of one side of a person's body by radiant heat, even although the other side of that person's body remained comparatively cold ; or, to put it another way, when a human body was being warmed by radiation it could still be comfortable, with a much lower air temperature than it might otherwise permit. That was one of the main reasons for the development of panel systems of heating during recent years.

He was glad Mr. Fowler had given such prominence to the effect of blending of coals. That was perhaps rather a highly technical topic, and often escaped, therefore, the interest and attention of most members ; but, as a result of the large amount of research work which had been carried out in recent years, very great improvements in the combustibility and in the general porosity and structure of coke might be expected within the next few years, because a very much bigger application of the principle of blending was being adopted by the gas companies at the present time.

Mr. Alcwyn A. Jones stated he was disappointed that the title of the paper had been altered and so eliminated reference to anthracite and other fuels. Personally, he thought all smokeless fuels should have been included in the paper. He was a great believer in the use of gas coke in most heating boilers, but at the same time it was not the only solid fuel which reduced air pollution. The author had given numerous tables in his paper, many of which were of more interest to the gas engineer, and it was, therefore, disappointing that the table which the heating engineer looked for was not given.

Perhaps the author in his reply would give a table showing the calorific value of cokes from vertical and horizontal retorts and coke ovens, and also low-temperature carbonisation.

In his Table IV the author gave the analysis of gas-coke and furnace-coke. Could he give the members a table showing the fixed carbon, volatile matter, ash, sulphur and moisture for low-temperature carbonised coke?

In connection with Table VIII he would like to know whether Mr. Fowler could explain why the efficiency of the low-temperature coke was less than that of the high-temperature coke, seeing that the low-temperature coke had less moisture and ash, a higher volatile matter, and a higher calorific value.

With regard to the behaviour under slow firing conditions, the author gave as an explanation of the failures in connection with coke fires in water boilers the fact that the fuel fell below its ignition temperature. He (Mr. Jones) believed that that did not apply in connection with low-temperature coke.

Table XII showed that the flexibility was improved by an increase in volatile matter. Consequently it was to be supposed that anthracite and low-temperature coke which had a much higher volatile matter than gas-coke—would give a better flexibility.

Clinker seemed to be a great trouble with gas-coke, as it appeared from the paper to require special firebars, water or steam sprays, or the use of chalk. Could Mr. Fowler give any comparative figures regarding the clinker of the high- and low-temperature cokes?

He had been rather surprised to read the author's comments under the heading "The properties desirable for coke for heating and domestic boilers." To him the author's remarks on this point seemed rather to bring out the disadvantages of coke for such purposes. Mr. Fowler said that efficient flexibility depended on small grades, which he had disparaged earlier on in the paper owing to the fuel falling through the grate bars and also owing to excessive clinker formation. Then the author's second property was large ash content, which reduced the rate of combustion; his third was the size of coke and the presence of shale, and the fourth was clinker troubles, which, he said, could generally be obviated by cooling the firebars. To his own mind all those seemed to be undesirable properties for coke for heating and domestic boilers.

Personally, he had found from experience that low-temperature coke had not the objections which had been mentioned. A number of people who had had trouble in keeping very small domestic boilers alight at night had now got over that difficulty (on his, Mr. Jones', suggestion) by using low-temperature coke instead. It required very little draught in order to keep it alight. His own boiler was stoked up the last thing at night; the damper was shut right down, and in the morning there was a large amount of fuel still alight, and warm water. There was no clinker to remove, and on adding a little fuel and shaking the ash down, the boiler went on functioning again quite merrily without there being any necessity to empty the grate, to relight the boiler or get clinkers out.

Dealing with coke for open fires, it had the disadvantage that a special grate was required. It had slow ignition. In the grate illustrated in the paper the hottest part of the fire seemed to be non-effective from a radiant heat point of view, especially as the grate fell towards the back away from the room. He supposed the reason for that was the desire to provide a gas jet in the front in order to get the best efficiency from the coke.

Mr. Fowler referred to the question of it being essential that coke fires should have a deep fuel-bed. He thought that earlier in the paper Mr. Fowler had mentioned the figure of 6 in. as being a suitable thickness.

Although he had made somewhat adverse comments on coke, he still thought there was a great use for it, and heating engineers would provide the gas companies with every opportunity of using all they could supply.

Mr. G. L. Copping said the recent fogs afforded ample justification for Mr. Fowler's paper. Any information which could be obtained on smokeless fuels was a real contribution towards the health of the population of this country.

At the commencement of his paper the author spoke about four or five centuries' supply of coal, and later on he referred to the comparatively limitless supply of coal, but went on to say that this fact was no justification for adopting uneconomic methods of using coal. Personally, he had often wondered whether it was of any real use considering half per cents. in the matter of the usage of coal ; it seemed to him that the Lady Bountiful was still in existence, and it was a question whether heating engineers should worry so much about the question of the economy of coal. Personally he did not think there was as much importance to be attached to economic methods of the usage of coal as was so often stressed.

Like Mr. Jones, he would like to have seen a little more information in the paper about the calorific values of the comparatively new smokeless fuels. It was really necessary to know what their calorific values were—and also the theoretical amount of air required for combustion per pound. Some idea, in a comparative form, of the combustion temperatures would also be very valuable. Heating engineers would then know what sort of draught to allow for, how much combustion space was necessary, and so on.

The author mentioned coalite and seemed to suggest that it was necessary to alter the ordinary domestic grate, and mentioned that 1 in. to 1½ in. size of coke was the best for open domestic grates. It was some time now since he (Mr. Copping) had seen coal; he had not had coal in his house for a good many years. He had been burning coalite in the same grate which he had had originally for many years for coal—with no alteration whatever; and the size of the coalite was often 4 in. or 5 in. in length. It was like a broken piece of the side of a cylinder in shape. He found that that burned perfectly well in the open grate, and it certainly gave very much less smoke. It also gave a fine glow and a good radiant heat.

Mr. G. Nelson Haden noticed that in Table IV the author gave the sulphur content as 0.9. Was that anything like a typical analysis for coke—not necessarily for London, but for the smaller coke-producing companies throughout the country? He would like to know also what importance the author attached to the sulphur content when it had been got down to something like that very small figure. From time to time one came across extraordinary cases of corrosion of wrought-iron boilers fired by coke; and if one found that the boiler had been reasonably treated (had not been allowed to stand with condensation on its inner surfaces and so forth) one had often been inclined to put it down either to a very high moisture content in the coke or to too much sulphur. Did the author think sulphur mattered very much when it had been got down to a figure like 0.9?

Mr. S. B. Chandler said the subject of the paper was a most important one bearing in mind the smoke and fog which were apparently inherent factors in the City of London particularly.

Mr. Fowler had not dealt with the financial aspect. Probably this did not arise in connection with the paper but from figures which have been made available to him (Mr. Chandler) it appeared that the running cost of coke fires as compared with coal fires was approximately one half. There was also an entire absence of smoke and dirt; these were very important matters from the point of view of the user. He did not know whether the author could confirm the statement he had just made.

A previous speaker had referred to what he might call the æsthetic quality of the coke fire. He had mentioned the fact that he wanted radiation—radiant efficiency—with his fire.

With a properly constructed coke fire one obtained, if anything, more radiant energy from it than from a modern coal grate and so far as the appearance of the fire went, there was no doubt that it was equal to that of the coal fire. The combustion of CO to CO_2 did produce an excellent effect.

Another point was with regard to the product itself and the low moisture and ash content. He thought that had been brought about very largely by the care which was now exercised particularly by gas undertakings, in the selection of coals for carbonisation. It was a fact, that in some instances there was an ash and moisture content clause in contracts which were made, which led to a coal being supplied which was reasonably low in both these constituents.

He desired to congratulate the author on the vast amount of information which had been given. The paper would well bear very careful perusal. The tables which had been given, despite the adverse criticism levelled against them, would be of very great use to heating engineers. So far as he himself was aware, this was the first time the subject had been dealt with in so comprehensive a manner.

Mr. F. F. Powell hoped he would not be out of order if he went a little beyond the scope of the paper ; but he did not see how it was possible to realise the importance or the advantages of coke as a fuel unless comparisons were made with that from which it was produced, i.e., coal. The paper, and most of the speakers, had dwelt very largely on the question of air pollution and its elimination by the use of coke. How far were they going to get even if all heating engineers recommended the use of coke? Not only in London but in every city in the kingdom, especially in the manufacturing towns, coal was being used as a fuel. Therefore, how far could smoke pollution be abated? It seemed to him that unless coke was utilised not only in the heating industry (which was a small industry compared with industrial process work) but in all industries, they would not get very far towards a solution of the problem.

Also, supposing for a moment that everyone decided to use coke. Would it be possible to supply it? One realised how impossible the situation would be at the moment if such places as power stations and huge factories all came upon the gas companies to supply them with their fuel. Hundreds of thousands of tons were used every year.

That was a part of the subject which occurred to him—that the uses of coke were very much limited, apart from the heating industry. He would like to ask the author if he could give some small comparison in regard to the matter. Personally, he knew that in one or two instances coal and coke had been used in power stations, and so far the result had not been altogether unsatisfactory. He would like to know if Mr. Fowler could give any information relating to that point.

Mr. F. J. Laws desired to refer to the remarks of a previous speaker who had dealt with the matter from the economic side. Personally, he looked at it from rather a different point of view, not at the economics of the quantity of coal in the country. From the point of view of combustion, if one was using raw coal one had to start first of all to distil off the volatile matter, which was a definite loss to the person who bought the fuel. What remained was virtually—coke.

Another speaker had mentioned clinker in boilers. He suggested that that gentleman had rather confused the issue, because as far as small boilers were concerned it was quite possible to make clinker from almost any type of solid fuel. It was, however, quite unnecessary to form clinker on any of these small boilers, if they were run correctly, with any type of high-temperature coke. He had personally seen coalite used in a small boiler, and he had seen taken from it, a large horse-shoe shaped piece of clinker. That was not the fault of the coalite ; it was simply the fault in the method of running the boiler. He did not think that clinker trouble could be levelled at coke, when a boiler was run correctly.

With regard to the question of supplying the amount of coke necessary, the supply was always regulated by the demand, and if there was a demand for thousands of tons more of coke he thought there would be no difficulty in providing it.

So far as the open fire was concerned, he had personally used coalite for some length of time. One of the objections to it was that the ash was so spread throughout the manufactured article that it showed itself as a deep coating over the whole of the fire, which spoiled the radiant heat which one would otherwise get, as with high-temperature coke.

As far as the central-heating boilers were concerned, it was not a question of clinker formation with high-temperature coke ; it was only that the author was dealing with those particular cases where the rate of consumption might be so high that clinker was formed ; but, generally speaking, there was no need to form clinker with coke.

Mr. T. G. Noble thanked the author for his very valuable summary of the subject and for showing the great changes which had taken place in one might almost say, the nature of coke, so that it was no longer just a cheap fuel, but a very definite fuel having very definite properties for various purposes.

He thought that one of the most striking points to which Mr. Fowler had drawn the attention of the Institution was the fact that an installation for complete central heating—that was to say, central heating to cope with the extreme conditions of temperature which were likely to be met with in this country—was not only undesirable from the point of view of ordinary health and comfort —for everyone knew that most people liked an open fire to supplement their central heating—but was an uneconomic proposition. He though that perhaps that was the point of view in which members of the Institution might be most interested. One was led, of course, to conclude that an installation of central heating combined with open fires burning solid fuels (preferably smokeless, of course) or gas or electric fires (the first-mentioned necessarily and the last two preferably in conjunction with a flue) was not only justified on account of its cheerful aspect, but was a very good economic proposition.

There were one or two questions he would like to ask, although the first might be outside the scope of the paper. He would like to know Mr. Fowler's views on the question of complete gasification as a possibly more fruitful subject for research than the production of alternative forms of solid fuel.

Secondly, he would like to ask the author whether the efficiency figures which Mr. Fowler quoted for domestic boilers were to be regarded as optimum figures or as average everyday working efficiencies. He assumed for the moment that they represented more or less the optimum efficiencies and were considerably above those normally obtained in practice.

Thirdly, he could not quite understand the reference to the importance of the kinetic energy of the gas in the ignition of coke, as it seemed to him that that did not depend on the air-gas ratio. Apart from small pressure losses when air was injected as primary air, the kinetic energy of the mixture, as far as he could see, must be more or less equal to that of the original gas.

Mr. L. W. Andrew mentioned that there were two points of detail on which he would like to comment. They both referred to the open coke fire. The first one was the sloping of the bars in a coke fire. In the diagram shown in the paper the bars of the grate-bottom sloped downwards from back to front. When he himself had first tested a coke fire he had thought he would only get a satisfactory result if the bars sloped downwards from back to front. He had then tested a coke fire in which the bars had sloped upwards from front to back, and he had obtained satisfactory results. Finally, he had tested a fire in which the grate-bottom had been level, and again he had obtained satisfactory results. The most important factor was the size and spacing of the bars, and not so much the slope.

If the bars sloped from front to back then there was inevitably a greater depth of fuel-bed before the fire was seen at all, and so, in practice, a much greater rate of burning was obtained with this arrangement of bars.

The other point was about the ignition of coke fires. He had done some tests some time ago on the optimum aeration of flames for lighting fires, and had found that an air-gas ratio of about 2 to 1 gave the best condition for lighting; but the effect of aeration had not been very pronounced. The really important factor was the actual gas rate. If the gas rate was above a certain minimum limit, the amount of gas used to ignite the fire was constant for a reasonable increase of gas rate. In other words, if the gas rate was doubled ignition was obtained in half the time. The important thing was to get above the minimum rate. It was worth referring to the gas poker for igniting open coke fires. The gas poker was a satisfactory method but a slow one. It did light the coke, but it took a long time for the coke to burn through in order to make a full fire.

In conclusion, he would like to touch upon a personal problem. He had at home a small " Ideal " boiler and two " Cleanglow " grates. He only wanted to keep one size of coke. Which would the author recommend him to keep ?

Mr. W. L. Boon said as being associated with Mr. Fowler he would like to raise one point, and that was the economics of the open coke fire. There were two definite schools of thought. Were they to provide a smokeless all-purpose fuel which was suitable for any grate, or were they to take the fuel which was available, namely gas-coke, and provide a grate for it ? What had they already got ? They had a smokeless fuel already prepared which could be used in any grate, but it was not prepared in anything like the quantity which was necessary for general use in all open fires. Therefore they had to make the best of the fuel they had. What were the actual economics as between the two fuels, as they existed to-day ? He could pay £2 for the purchase and installation of a fire-grate in which he would use gas-coke, and he could purchase his fuel at 40s. a ton. Otherwise he could use coalite in his ordinary grate and pay 60s. a ton. He thought the economics of the matter were rather obvious !

Further, he thought that, as civilisation progressed, smokeless fuel must be used. That seemed absolutely definite in the natural order of progress. Coal could not be continued to be used as it had been used in the past. London, he submitted, had the unenviable reputation of being the dirtiest capital in the world—and he had been in most of the capitals of the world and had seen this for himself. He thought, too, that it must be admitted that domestic grates were more responsible for that state of affairs than industrial plants. There was a certain degree of legislation which protected the population from the smoke from industry, but there was no legislation which protected it from the domestic chimney. In travelling on the Southern Railway and coming into London from Dover he often wondered what foreign visitors thought of the aspect—one long vista of frightful chimneys, a reception to England of which he felt ashamed. He remembered one American lady on her first visit to this country asking him, " What on earth are those small things poking out of all the houses ? "

Referring to the question of industrial boilers, a matter had been raised as to the use of sprays below the grates. Sprays were only used when the boiler had to be forced—when a high output had to be obtained from it, which output normally was perhaps unnecessary.

In central-heating work sprays, either steam or water, were normally not used and not required. With a forced and higher output there appeared the clinker disability which existed with the fuel, but the adhesion of clinker to firebars could be overcome effectively and easily, and at very little cost, by that very simple means.

Mr. G. R. Jackson, referring to Mr. Fowler's mention of the reduction in the formation of clinker through cooling the firebars by means of water spraying, said he thought some of the members present would also like to have the author's observations regarding the effect on the formation of clinker through the use of waterway firebars.

Mr. L. J. Fowler, in reply, said he appreciated the thought which prompted Mr. Jones' critical outburst, but he was not rising to the bait. When he had started to write the paper he had set out to give information and not to give comparisons. Personally, he thought that in the Institution, and elsewhere, in the last few years there had been too much energy expended by people in the position in which he himself was that night, comparing products in which they were interested, with other people's products. Information given under such circumstances had an inevitable bias. That evening he had given some information on one product which was comparatively new information to him. Mr. Grierson would to-morrow night at the Institution of Electrical Engineers give information on another product. He felt that it was better that in each case the information should be given for what it was worth, and that the public should assess the relative values of the respective products. He therefore did not set out to offset coke against coal, electricity or gas. That was why he had made no reference to anthracite and other smokeless fuels.

When he had started to write the paper he had had a much greater belief in the future of low-temperature carbonisation than he had at the present moment, and he had written a good deal about that. He had shown what he had written to people with a more intimate knowledge, and they had discounted most of it. He had therefore cut out everything except the bare references which he had just given.

Replying to Mr. Jones' request for calorific values, the majority of cokes have a value exceeding 13,000 B.T.U. per lb., and a safe working figure is 12,500. The calorific value of semi-coke is usually about 13,000, and a typical analysis is :—

Volatiles	14.1 per cent.
Ash	14.6 „
Moisture	1.7 „
Fixed carbon	69.6 „

A reference had been made to clinker. As Mr. Boon had said, clinker was only a source of trouble when it was necessary to force boilers. Quite frequently a boiler was put in for a certain load, and after it had been in for some years the load was increased. The owners did not want to put in a new boiler, and the output from the boiler had to go up with the load, and forcing became necessary; and he had just given hints to indicate how forcing could be undertaken without trouble.

One speaker had mentioned complete gasification. Quite frankly, he knew nothing about it except the brief references given in technical papers. Apparently in Germany it was considered, at any rate by Dr. Bergius, an economic success, and the Government considered it as such, otherwise they would not have subsidised the Billingham plant.

On the question of open fires, semi-cokes could be burned sucessfully in most of the standard grates. There was no doubt that with high-temperature cokes better results were obtained if the precautions to which he had referred were taken.

With regard to sulphur, the analysis given was typical. Similar types of coal were carbonised throughout the country, and the sulphur content of the product was fairly constant. Regarding its effect on boilers, he did not think it mattered much whether the sulphur content was 0.9 per cent. or 0.13 per cent. or 0.7 per cent. If the flues were kept dry there was no trouble experienced. If there was dampness one would get trouble, but he did not think that that trouble would vary much according to slight variations in the percentage of sulphur.

Mr. Powell had mentioned coal and coke in power stations. That again was a subject upon which he himself was not expert. Cheap coals were obtained by the power stations at very low figures, even down to 12s. a ton and less, and in a number of instances coke breeze was burned by means of the sandwich system; an automatic stoker fed the two fuels in together. That had been done for some years with great success.

Regarding the figures he had given in the table showing boiler efficiencies, he had been rather hesitant to show those because he was not a great believer in efficiency figures. (There were certain boilers now advertised as giving 95 per cent. efficiency.) He had given them, however, for considered comparably they were valuable. They had been taken in a small domestic boiler, and most of the heating surface was direct. That was the reason why the high-temperature fuel gave a higher efficiency than the low-temperature fuel, and the semi-anthracite coal. In the latter cases there was undoubtedly a higher flue temperature.

Referring to the remark in the paper about gas fire ignition and kinetic energy, he wished to make the point that the gas flames must be projected some distance under the coke. His mathematics were not as good as they were, and "momentum" was probably a more correct term than "kinetic energy."

Mention had been made of the sloping of the bars of open grates The grate which he had depicted in the paper had the bars sloping from the front down to the back. There were other apparatus with horizontal bars, and some in which the bars sloped the other way. He had had the privilege of seeing at the Gas Light & Coke Company's works at Fulham a range of six coke grates of different makes, and there was no doubt that the grate which he showed in the paper looked most attractive. The others did not have such an even glow, and his impression was that the amount of heat radiated from them was not as great.

Referring to the problem of a boiler and an open fire, and of two grades, the smaller grade would burn in a fire much more than the larger size would burn in a small boiler.

Mr. Jackson had referred to waterway bars. They undoubtedly had a cooling effect which retarded clinker. He would be very pleased to see if he could get some figures which would be of assistance. (Tests are being considered.)

Mr. C. R. Allensby then proposed a very hearty vote of thanks to Mr. Fowler for the excellent paper he had given the Institution that night. It was a paper of extreme importance to the members. It had met with some criticism and with a good deal of discussion, but he thought Mr. Fowler would be pleased, because it showed the interest which it had created amongst the members. For generations to come, the question of coke would always be one of direct interest to the Institution, because it was a fuel which was economic and smokeless ; and the question of knowing how to burn that fuel in the most scientific manner must always be of great interest to heating engineers.

He thought the members could look forward to another paper on the subject in the near future, because so much progress was being made in the matter of coke and its combustion that the present methods of combustion would probably become out of date, and the burning of coke put on a still more scientific basis than it was on at the present time. The members would therefore look forward to future papers on a similar subject.

The vote of thanks was carried by acclamation, and the meeting terminated.

SOME RECENT IMPROVEMENTS IN BOILER PLANT FOR CENTRAL-HEATING AND HOT-WATER SUPPLY

DISCUSSION

Norman Wignall (communicated). As one who was unable to take part in the discussion which followed the reading of Dr. Taylor's paper on " Some Recent Improvements in Boiler Plant," I should be pleased if I may be allowed to reopen the discussion by correspondence.

I must congratulate Dr. Taylor on his very excellent paper, and on the good work he has accomplished in the development of the automatic boiler for solid fuel.

One point raised by him in the discussion, however, I feel compelled to criticise, namely, the reference to " boilers . . . with forced draught under the grate, which directed a pressure right up through the hopper." Dr. Taylor is surely under a misapprehension in this respect, and perhaps he will be able to make his criticism of such boilers clearer if he would kindly oblige by stating exactly what he himself understands by the term " forced draught." The general conception is that it applies to any furnace where the draught is increased by mechanical means for the purpose of obtaining comparatively high rates of combustion, thus effectively dealing with larger quantities of fuel per square foot of grate area per hour than would be possible with the normal chimney draught ; alternatively, the increased draught may be used for the purpose of effectively burning inferior qualities of fuel, the nature of which set up comparatively high resistance through the fire-bed.

The writer knows of no gravity-fed boilers for central-heating purposes where such conditions are imposed, and can only conclude that Dr. Taylor refers to boilers where " controlled mechanical draught " is applied, a very different matter indeed. In these cases the draught is supplied to the ashpit by means of a small centrifugal fan driven by electric motor, and the system is adapted purely and simply for the reason that the electric motor can be easily placed under thermostatic control by either immersion thermostat, pressurestat, or roomstat. Within the writer's knowledge, no attempt is made to increase the rate of combustion over that usually found in any heating boiler, therefore the term " forced draught " does not apply. In addition, makers of such boilers never under any circumstances pretend that the fan will replace the usual chimney (although in such cases the chimney simply serves the purpose of exhausting the products of combustion from the combustion chamber of the boiler, and not to provide the draught through the fire-bed).

There is, therefore, no reason why there should be any greater risk of escaping CO with this class of boiler than with the type favoured by Dr. Taylor, where chimney draught alone is utilised.

In fact, one must ask whether the risk is not greater with the latter, since the control is obtained in this case by closing or opening the boiler damper by means of a pulling motor under automatic control. What happens when the boiler damper is closed? A certain quantity of gas is surely being generated for some time from the surface of the fire, with a good chance of being bottled or pocketed in the boiler. It is understood, of course, that the dampers are made so as not to close properly, but what happens when the flue in which the damper is located becomes partly made up with soot, or dirt, due to neglect? At least, the boiler under "controlled mechanical draught" has the advantage in that the boiler damper is either omitted completely, or locked in the open position.

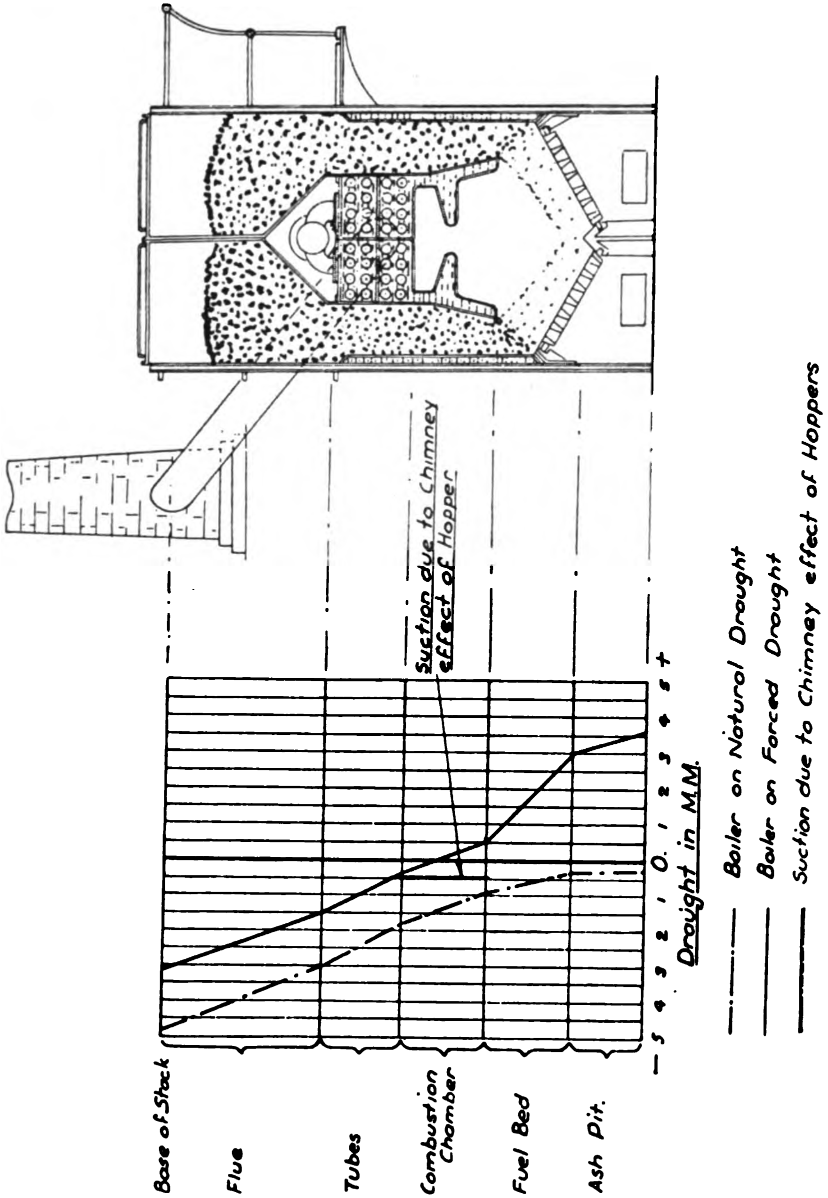
Dr. F. M. H. Taylor, in reply, writes: Mr. Wignall has drawn attention to a matter which is one of the utmost importance from the point of view of boiler design and layout.

Before discussing the merits of controlled forced draught as distinct from controlled natural draught it is necessary to assume that certain conditions attach to the forced-draught installation. Unless the chimney pull is weak or the resistance of the fuel-bed or of the flue tubes in the boiler is high, whether by design or accident, the necessity for forced draught does not arise, and there is no point in going to the extra expense if a perfectly adequate supply of natural draught is available. It is, of course, assumed that reference is made to automatically-controlled forced draught or natural draught according to one or other of the well-established systems.

Assuming, however, the desirability of controlled forced draught has been established, the air pressure through the ash-pit, the flue, the combustion chamber and to the stack must be considered. This is illustrated in the accompanying diagram showing actual readings on a natural-draught installation compared with a forced-draught boiler where the loss of pressure through the boiler must be higher or the chimney pull lower than for natural draught.

As Mr. Wignall has rightly pointed out in the *Heating and Ventilating Engineer* (December 1934), the pressure in a combustion chamber is approximately balanced and will therefore be definitely higher than that in the natural-draught boiler.

The fuel hopper, containing warm gases, will exert a chimney effect equivalent to the height of the hopper times the difference in density between the cold atmospheric air and the warm air inside


Suction due to Chimney effect of Hopper
Base of Stack
Flue
Tubes
Combustion Chamber
Fuel Bed
Ash Pit.
− 5 4 3 2 1 0. 1 2 3 4 5 +
Drought in M.M.
Boiler on Naturol Drought
Boiler on Forced Drought
Suction due to Chimnay effect of Hoppers

the hopper. This will tend to give a small pull in the combustion chamber, represented by the thin double line on the graph. It will be seen that the pull from the natural draught is greater than this ; in other words, there is no tendency to draw gases up the magazine. The resulting effect is a reverse pull down the hopper, so that if a leakage occurred on the top of the hopper, air would be drawn in rather than gases escape upwards.

READINGS TAKEN IN A NATURAL-DRAUGHT HOPPER-FED BOILER

Pulls in mm. w.g.

Stack	4.80
Flue	4.50
Rear of Tubes	3.05
Front of Tubes	1.70
C.C.	0.95
Ash Pit	0.40

Where forced draught is employed, however, and the combustion chamber is balanced, it will be seen that the chimney effect of the magazine tends to give a lower pressure in the combustion chamber. Hence, should the lid be open the gases would flow up the magazine. I am not asserting that there is any certainty that carbon monoxide will be sent out into the boiler-house, but merely point out there is definitely the possibility that this might occur in controlled forced-draught installations.

One further point which Mr. Wignall raised is that natural draught requires an open chimney damper. In point of fact the damper is so arranged that it never quite closes, so that there is sufficient pull on the boiler to sweep out any gases formed even after the primary air is shut-off.

There are a number of points of difference in connection with the operation of controlled natural and forced draught, but I assume that these are not relevant to this discussion.

BUILDING RESEARCH STATION, GARSTON, NR. WATFORD, HERTS.

THE MEASUREMENT OF THE RATE OF AIR CHANGE

By W. G. MARLEY, M.Sc.

Introduction.

FOR some considerable time the need has been felt of a simple method of measuring the rate of ventilation. A knowledge of this quantity is valuable in the design of heating systems, but in the majority of instances only a vague estimate of it has hitherto been possible. Occasionally, the air velocity in supply ducts can be measured, but frequently a system of ducts is not employed and the task of determining the rate of air change becomes one of considerable difficulty.

In experiments conducted at the Building Research Station in 1927[1], the ventilation of a room was determined by measurement of the increase in carbon dioxide consequent upon the burning of three standard candles for three hours. A 2.5 litre sample of air was taken by means of rubber hand-bellows, the flask being moved round the room about 3 ft. 6 in. from the floor, and the carbon dioxide was estimated by absorption in barium hydroxide and titration of the excess with oxalic acid. Using this method of measurement the efficacies of an unheated flue and a wall ventilator were compared.

---

[1] Report of the Building Research Board for the Year 1927, p. 102.

Experiments have been made to investigate the possibility of utilising the rate of supply of steam, necessary to maintain an increased water content in the air of the room, as a measure of the rate of ventilation.[2] This method proved unsatisfactory, however, owing to the absorption of water vapour by the walls, and furniture of the room.

Hydrogen Method.

A simple accurate method has now been devised, based upon the fact that, if a small quantity of hydrogen be released into the air of the room, the rate of decay of concentration affords a measure of the rate of air change.

The thermal conductivity of hydrogen is seven times that of air and, consequently, traces of this gas in air can be readily estimated by a careful measurement of the thermal conductivity. This is conveniently performed with a katharometer, an instrument devised by Shakespear[3] and now used commercially for the determination of carbon dioxide concentration in flue gases.

The Katharometer.

Two spirals of platinum wire R_1 and R_2 (Fig. 1) having identical resistances, are enclosed in separate cells A and B, which are located in a solid copper block to ensure their being at the same temperature. Each spiral forms one arm of a Wheatstone bridge circuit, while two

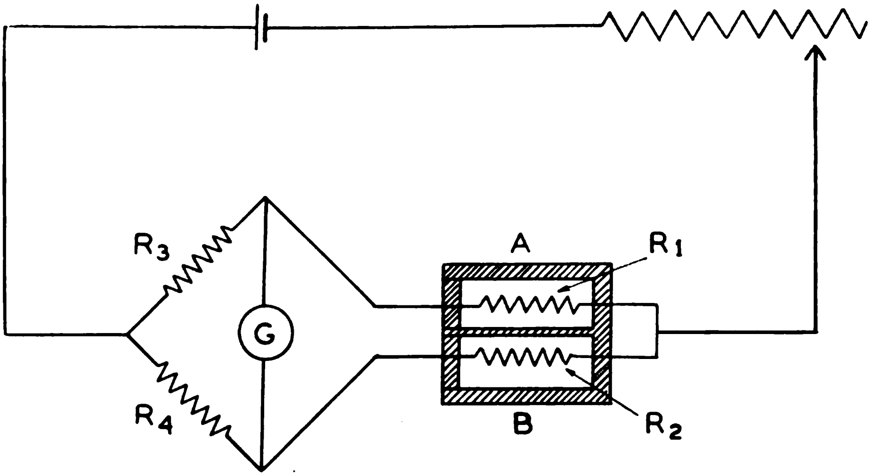


FIG. 1.

---

[2] Dufton, A. F., and Marley, W. G., *Journ. of Inst. of Heating and Ventilating Engineers*, 1934. Volume I. pt. 12. p. 645.

[3] Shakespear and Daynes. *Proc. Roy. Soc.*, 1920. Vol. A. 97. p. 273.

other identical resistances R_3 and R_4 complete the bridge. A definite electric current flows through the bridge, heating the spirals, which in turn lose heat, through the gases surrounding them, to the walls of the cells. A standard gas—normal air—is trapped in cell A, which is sealed. The air of the room diffuses into cell B continuously and the change in its thermal conductivity due to the trace of hydrogen causes spiral R_2 to vary in temperature and, therefore, in resistance compared with spiral R_1. This unbalances the bridge producing a deflection in galvanometer G and this deflection is a measure of the change in thermal conductivity of the air, and therefore, of the concentration of the hydrogen producing that change. The actual instrument used gave a deflection of approximately one inch on the galvanometer scale for a change in concentration of 0.1 per cent.

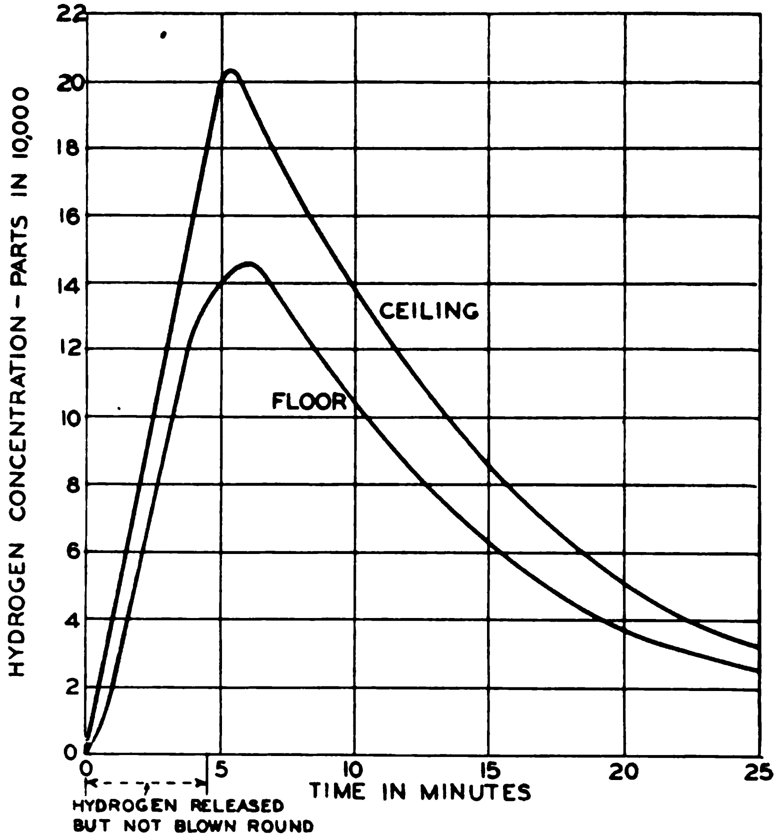


FIG. 2. HYDROGEN CONCENTRATION CURVES.

Development of the Method.

With a gas of the nature of hydrogen care must be taken to ensure that the concentration never reaches the explosive limit of 9 per cent. In these experiments the maximum concentration employed was 0.2 per cent. Other gases could be used, notably carbon dioxide, but hydrogen is fifteen times as effective and diffuses five times as fast.

The concentration of hydrogen tends to be greater near the ceiling. Experiments have shown that when the gas was simply released from a cylinder the subsequent concentration at floor level was about 70 per cent. of that at ceiling level. This proportion remained sensibly constant as the amount of hydrogen decreased (Fig. 2) and, consequently, the measured rate of ventilation is independent of the height of the katharometer above the floor. With such a gradient of concentration, however, the amount of hydrogen in the room would decrease more rapidly if the room were ventilated by extracting air near the ceiling than if the air were extracted near the floor, and a different figure would thus be obtained for the rate of air change. The hydrogen was therefore released into the horizontal air stream from an electric fan, which was run only while the gas was being admitted. A much more uniform concentration was obtained in this way and the measured rate of air change was reasonably independent of the height of the exit.

The Accuracy of the Method.

In order that the possibilities of the method could be readily explored, a fan was arranged to extract air from the room and deliver it to the outside through a duct. With such an arrangement all other apertures became inlets and the air flow could be computed from the pressure drop across an orifice plate in the duct. In the table below a comparison is shown between the rate of air change so calculated and that measured by the present method, with various sets of conditions.

In these experiments the air was removed from the room at one point, situated near the floor or near the ceiling ; the conditions were consequently more stringent than would be encountered in practice and the good agreement in the results of experiments 3 to 7 is regarded as highly satisfactory.

When a room is occupied, the concentrations of carbon dioxide and water vapour increase and both these substances affect the katharometer slightly. In order to minimise errors due to these changing concentrations the number of persons in the room was kept constant during and immediately prior to an experiment.

Experiment No.	Air changes per hour from orifice plate method.	Air changes per hour from hydrogen method.	Suction point of fan.	Remarks.
1	7.0	6.2	Floor	No circulating fan while hydrogen was admitted.
2	7.0	8.1	Ceiling	
3	7.5	7.0	Floor	Hydrogen blown round room with fan.
4	7.5	7.5	Ceiling	
5	7.7	8.0	Floor	Ditto. Air-brick ventilator open.
6	7.7	7.5	Ceiling	
7	4.0	4.1	Floor	Comparison at lower rate.

Experimental Procedure and Calculation of Results.

In the conduct of an experiment the katharometer is placed as central as possible in the room and an electric fan arranged to circulate air at floor level. Hydrogen is admitted to the air stream of the fan till the katharometer indicates a concentration of 0.2 per cent. The fan is switched off and the katharometer read every minute for some twenty minutes. The readings are plotted on semi-logarithmic graph paper and a straight line drawn through them.

If a room be ventilated at a constant rate the amount of original air decreases exponentially. When a volume of air equal to p times the volume of the room has been introduced, that is after p air changes, the volume of original air remaining is equal to e^{-p} times the original volume, thus :—

p	0	$\frac{1}{2}$	1	2	3	4
Volume of original air, per cent. ..	100	60.7	36.8	13.5	5.0	1.8

From the graph of the observations of hydrogen concentration it is possible to read the number of minutes taken for the concentration to fall to 36.8 per cent. of its value at any time ; this is the time of one air change.

NEW BOOK:
ELECTRIC HOT-WATER SUPPLY

Electricity is entering so much into every branch of engineering that it is not surprising that the electrical engineer should now look for further expansion by designing methods of providing hot-water supply and even providing a paradox in that electricity being produced from steam power can seemingly be used to generate steam again to advantage. Electricity is now established as one of the fuels to be considered by heating engineers and consequently there is naturally an opening for this book,* for heating and electrical engineers, which describes the use of electricity in connection with hot-water supply. In its eight chapters, well illustrated, the author has provided information on electric water heaters, their installation for large and small buildings and even swimming pools. The first chapter on temperature measurement unfortunately requires considerable revision, as amongst other items the figures in Table 4 seem to be incorrectly quoted from the I.H.V.E. Bulletin No. 1, Table 5 has figures which do not agree with common practice, the formulæ for heat loss by convection and total heat loss are wrong and it is confusing when in one formula we find T and A representing absolute temperature and coefficient, whilst in another they represent thickness and area, and two symbols Q and H are used to refer to heat loss per square foot per hour, though " square foot " is omitted in two references. Chapter 2 deals with electrical fundamentals, resistances, heating elements and thermostats. Heating water by electricity is considered in Chapter 3 and examples are given of the method of calculating the load required and efficiency and the question of geysers versus storage heaters is discussed. In the examples the figure 3,400 B.T.U. per kWh is used instead of the accepted 3,412. The next two chapters deal fully with electric hot-water systems—dead-leg, circulating and indirect—and scale formation, and the economies of electric hot-water installations. In comparing circulating systems it is noticed that in Figs. 34 and 36 the return pipes are shown entering the bottom of the cylinder instead of near the top, as shown in Fig. 37, giving an improved circulation, but providing cooler water at the outlets, even if the return is reduced in size, because water is drawn from both the flow and return when taps are opened. The technical aspect of fitting electric-heating elements to existing hot-water systems is dealt with in Chapter 6 and it is pointed out that such conversions cannot have the same high working efficiency as those of specially designed electric storage water-heaters. Chapter 7 discusses the use of electric energy for swimming baths, as the introduction of filtration and water treatment now enable the same water to be used throughout the season and consequently provides a more economical heating problem. Information is given enabling the load to be calculated. The increase of indoor and outdoor baths makes this chapter one of interest. The last chapter deals with electric steam generation, boilers, immersion heaters, tubular and electrode. The electrode boilers being available for both hot water and steam production are usually adopted for thermal storage heating systems, but seldom used for hot-water supply. Other applications of electric steam heating are also dealt with. Revision is also needed in the useful hydraulic notes given at the end of the book, the gallons and pounds of water in one cubic foot do not agree with the figures given in Table 2 and the formulæ for capacity in gallons of cylinders and the surface area of cylinders in square feet are incorrect. It is to be hoped that in future editions the necessary revisions will be made to an otherwise useful book.

---

* " Hot-Water and Steam Supply by Electricity." By Frank C. Smith, A.M. I.H.V.E., A.I.E.E. 5½ in. × 8¾ in. 142 pp. 62 illus. Cloth. Published by E. & F. N. Spon Ltd., London. 1934. Price 7s. 6d. net.

HEATING AND VENTILATING INDEX

Steam Heating. 697.52

Steam Heating Systems Classified to Facilitate Modernising Work. Harold L. Alt. 4½ pp., 10 illus. Review of various types of steam-heating systems : *Plumbing and Heating Trade Journal*, U.S.A., September 1934.

Scale. 621.194.4

The Thermal Influence of Boiler Scale. E. A. Smith. 2 pp., 2 illus. Dealing with influence of deposited scale on the transfer of heat through boiler plates and effect on fuel consumption : *The Fuel Economist*, September 1934.

Air Conditioning. 697.96

Air Conditioning for Heating Contractors. L. L. Simmons. 2½ pp. Dealing with selection and design of steam jet refrigeration equipment : *Bull. Heating, Piping and Air Conditioning Contractors Nat. Assoc*, U.S.A. September 1934.

Scale. 621.194.4

Scale in Steam Boilers. E. A. Smith. 1½ pp., 3 illus. Dealing with the effect, formation and prevention of scale : *The Steam Engineer*, October 1934.

District Heating. 621.312

District Steam Heating. B. M. Conaty. 2 pp., 2 illus. Discussing the future of district heating : *The Steam Engineer*, October 1934.

Flow of Fluids. 536.74

What Gas Engineers Should Know about the Flow of Fluids. 2½ pp. Dealing with fluid flow, friction and factors : *The Gas Engineer*, October 1934.

Ventilation. 697.9

Calcul de la ventilation des locaux industriels dans lesquels se produisent des dégagements de vapeur d'essence. A. Reykenberg. 4 pp., 3 illus. Explaining calculations for ventilation of industrial rooms in which oil vapours are given off and which may cause fires : *Chauffage and Ventilaticn*, September 1934.

Comfort Conditions. 697.96

Instruments destinés à repérer le confort au point. de vue du chauffage. G. Prud'hon. 5 pp., 2 illus. Dealing with the question of comfort and the use of the eupatheoscope and kata-thermometer : *Chauffage and Ventilation*, September 1934.

Comfort Conditions. 697.96

How Comfort is Measured by Effective Temperatures. Harold L. Alt. 4 pp., 5 illus. Discussing the use of psychometric curves and use for arriving at comfort conditions : *Domestic Engineering*, U.S.A., October 1934.

Farm Buildings. 728.94, 728.95

Ventilating and Heating of a Modern Farm Building Group. Alfred J. Offner. 3½ pp., 4 illus. Describing data for heating and ventilating various types of farm buildings : *Heating and Ventilating*, U.S.A., October 1934.

Insulation. 536.2

Metallic Heat Insulation. E. R. Queer. 5 pp., 4 illus. Dealing with heat transfer, experimental determinations and discussion of results : *Heating and Ventilating*, U.S.A., October 1934.

Combustion. 621.182

Automatic Heating Systems. George H. Hirons. 2½ pp. Dealing with calculations in connection with combustion : *Heating and Ventilating Engineer*, October and November 1934.

ABSTRACTS

Metallic Heat Insulation. 536.2

1. Low emissivity materials such as clean metallic foils form excellent low density heat insulators *when facing air spaces.*

2. A single sheet of bright aluminium foil suspended in an air space will produce approximately the same insulating effect as 1 in. of board or blanket form of insulation, both having the same air space advantage.

3. An air space (¾ in. to 3⅝ in. in width) bounded by a conventional building material on one side and a bright aluminium surface on the other will have a conductance of 0.404 B.T.U. per sq. ft. per hr. per °F. at 70° mean temperature.

4. Although crumpled foil has the advantage of being easy to apply to the surface contour of the article to be insulated, it has a higher heat transfer coefficient than the plane spaced sheets.

5. Since atmospheric dust pollution is prevalent in industrial communities good sealing* is required for metallic insulation, otherwise dust, soot, and condensation will seriously impair its insulating qualities. In refrigeration work hermetic sealing is required to exclude moisture.

6. Lacquer which has an emissivity of 0.90 if applied in a thin enough layer will not seriously affect the emissivity of metals for insulation purposes.

7. Full finished tin mill black steel plate makes good metallic heat insulation providing corrosion can be avoided. (E. R. Queer, *Heating and Ventilating.* October 1934.)

Heat Emission from Ducts. 697.9

Different types of surfaces and insulations have different "emissivity coefficients," that is, heat emission factors. These are given in the number of B.T.U. transmitted per hour by a surface a square foot in area when the temperature difference between the inside of the surface and the air around it is one degree F. This is discussed in the University of Illinois Engineering Experiment station bulletin No. 117, from which the emissivity coefficients given in Table I are taken.

The emissivity coefficients are for duct temperatures. Using the temperature of the air in the duct as the duct temperature introduces a small error which tends to give slightly lower values for final temperature difference than actually obtains. The difference amounts to only a few per cent. and is on the side of safety. Values

---

* This insulation is enclosed within the building structure as it is installed in practice, and this assists in sealing and reduces pollution of the insulation. Other insulation forms usually require sealing against moisture.—*Editor,* "*Heating and Ventilating.*"

TABLE I.

EMISSIVITY COEFFICIENTS FOR TIN AND GALVANISED IRON DUCTS.

No.	Description of Covering or Surface.	Tin.	Galvanised Iron.
1.	Bare, no insulation	1.28	1.33
2.	One thickness of air cell asbestos and one of 10-lb. asbestos paper	0.87	0.90*
3.	Three thicknesses of ¼ in. air cell asbestos and one of 10-lb. asbestos paper	0.565	0.577
4.	12-lb. asbestos paper, one ply ..	2.08	2.10*
5.	12-lb. asbestos paper, two ply ..	1.88	1.90*
6.	12-lb. asbestos paper, six ply ..	1.39	1.42*
7.	12-lb. asbestos paper, eight ply ..	1.26	1.29*

* Estimated by comparison.

of emissivity on the basis required for heating work are not available. (J. Donald Kroeker, *American Artisan*, November 1934.)

Heat Transfer from Fluid inside Pipe to Walls. 536.2

The following formula of McAdams is suitable for the turbulent flow of gases (including superheated steam) water, oils, and other liquids flowing at $\frac{DG}{u}$ above 10,000.

$$h = \frac{G^{0\cdot8} K^{0\cdot6}}{D^{0\cdot2}} \left(\frac{Cp}{u}\right)^{0\cdot4}$$

where h = transfer coefficient B.T.U. per hr. per sq. ft. per deg. F.

D = inside diameter of tube, feet.

K = thermal conductivity B.T.U. per hr. per sq. ft. per deg. F. per ft.

G = weight velocity, lb. per hr. per sq. ft. of cross section.

u = viscosity, lb. per hr. per ft.

Cp = specific heat B.T.U. per lb. per deg. F.

The physical properties are to be evaluated at the average temperature of the fluid (not of the film). This is the arithmetic mean of the temperatures of the fluid entering and leaving the apparatus. (Frederick H. Roberts. *Jour. Inst. of Engineers*, *Australia*, July 1934.)

INSTITUTION OF HEATING AND VENTILATING ENGINEERS

REPORT

SESSIONAL MEETING, LONDON, JANUARY 9th, 1935.

A Sessional Meeting of the Institution was held in the Lecture Theatre of the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1, on January 9th, 1935; the President, Mr. R. C. Ching, in the Chair.

There were over eighty present; the following signed the attendance register: Messrs. T. C. Chatterton, A. Fleming Browne, Frank Selley, A. W. Beaven, D. A. I. Anderson, J. G. Ford, T. E. Barnes, W. G. Case, T. H. S. Hatchett, H. Fitch, R. Grierson, J. H. Bryant, J. C. Byles, F. S. Reed, J. W. Stitson, S. I. Saunders, J. L. Waller, G. L. Copping, W. E. Brown, E. L. Joselin, C. R. Allensby, J. W. Cooling, R. C. Ching, J. A. Kemsley, T. A. Worsdell, A. C. F. Mackadam, T. Ault, E. D. Kelly, P. W. Glover, Harry Merrin, W. L. Cowie, C. Geo. Nobbs, Edwin Osborne, W. H. Dupen, L. Copeland Watts, H. E. F. Heath, L. A. Baines, Louis A. Forni, T. J. Noble, Geo. A. Pullen, T. W. Dunkley, E. B. Darby, H. Moore, A. C. Mann, S. K. Ives, H. N. Blake, A. Hunt, Geo. F. Rider, Alcwyn A. Jones, B. A. Pountney, J. N. Bottrill, C. W. Tidy, G. T. Carter, W. Ferne, S. Adams, A. J. H. Binns, and H. B. Watt (Secretary) (London); T. H. Wakeling (Croydon); S. Naylor (Halifax); Walter Yates, Oswald Stott (Manchester); Robert H. Rowell (Newcastle-on-Tyne); and visitors: Messrs. T. Gilchrist, J. Renard, A. H. Harwood, A. Arnold, C. Holgate, J. Wainwright, T. A. Patterson, B. C. Oldham, L. G. W. Gosden, G. W. Ferry, A. A. Bissett, J. C. Hosken, W. Dieterichs, F. W. Garrard, G. Vivian Davies, R. G. Brocken (London); and E. M. Taylor (Christchurch, New Zealand).

The President, in opening the meeting, remarked that since the meeting was the first to be held in 1935, he took the opportunity to wish all those present a happy, healthy and prosperous New Year.

There was no need for him, he said, to introduce the reader of the paper, Mr. Fleming Browne. Mr. Fleming Browne had been a member of the Council of the Institution for many years, and was well known to all the members.

Mr. A. Fleming Browne, M.I.Mech.E. (Member), then read his paper on "Air Heaters for Heating, Ventilating and Drying," which was illustrated by lantern slides.

AIR HEATERS FOR HEATING, VENTILATING AND DRYING

By A. FLEMING BROWNE, M.I.Mech.E. (Member)

SESSIONAL MEETING, LONDON, JANUARY 9th, 1935

When the author became connected with the heating and ventilating business, about a quarter of a century ago, air heaters were not nearly so largely used as nowadays. Air conditioning was in its infancy and heaters were mainly required in connection with drying plants. Little or no scientific data was to be found in any text-book giving any formula for calculating heating surface required for a specific duty. Generally speaking, rule-of-thumb methods prevailed, and the few heater manufacturers who existed kept to themselves any information they had acquired.

The types of heaters on the market were either of cast-iron gilled pipe or of 1 in. plain tube, either wrought-iron or steel, with screwed connections and heavy cast-iron bases; there was also the hairpin or U-type pipe-coil heater with cast-iron base into which the tubes were fixed and expanded. There was then also on the market, Row's indented steel tube, made up into heaters by Messrs. Royles, this heater being largely used in the textile trade and suitable for high-steam pressures. A still older design of tubular heater was also used in connection with drying plants, and is still used, made on the lines of a " surface condenser," the air being blown through the tubes and the steam being on the outside. The " Vento " cast-iron sectional heaters had also arrived, for use with hot water or low-pressure steam, and this type was the one mainly used in plenum heating installations.

Other makes and types were no doubt available, or in use, but the foregoing were in common or general use.

For some ten or twelve years there seems to have been little or no change or progress made, at least in this country, as regards producing new and improved designs. No doubt the War period distracted attention, and manufacturers had no time to devote to experimental work for producing new types or designs.

In 1920, the author became more actively interested in the design and manufacture of heaters, and found that there was still, even at that date, little or no scientific data in any English text-book on the subject of heat transfer which could be usefully applied.

The American Radiator Co., as it was then called, had published their *Data Book*, one of the best and most useful catalogues of heaters published up till then, and possibly even now not surpassed, for completeness of information.

In America, however, Carrier & Busey[1] had read a paper on air-conditioning apparatus, to the American Society of Mech. Engineers, in which paper a curve was given showing the heat transmission of pipe-coil heaters per square foot of heating surface per degree difference between mean temperature of air and temperature of the heating medium. This was afterwards followed by the publication of Harding & Willard's book[2] on heating and ventilating, in which the Carrier curve was reproduced and also curves for Vento heaters. These curves were most useful, and are still a most useful basis for heater calculation, though they are not, in the light of more recent knowledge, strictly accurate as will be mentioned later. Harding & Willard also stated that the mean logarithmic temperature of the air should be taken, a fact the author thinks not previously stated by other authorities.

The author, therefore, came to the conclusion, since justified, that any table of heat transfer or temperature rise which had to be prepared in order to calculate the size of heater for any specific duty or enquiry, could only be satisfactorily made from actual tests of the particular design of heater used. These tests were subsequently carried out and used in the compilation of a catalogue.

Heat Transfer.

It is not the author's intention in this paper to deal with the scientific side or theory of heat transfer as applied to air heaters. A bibliography at the end of the paper gives the names of some useful books and papers on the subject which have been mentioned, for those who wish to pursue the study of the matter.

During recent years, a considerable amount of research work has been carried out both at home and abroad. Unfortunately, however, the information obtained has not generally been presented in a sufficiently condensed and simplified form as to be of much service to the heating and ventilating engineer, and also, in the author's opinion, the tests which have been made, have not, in most cases, been carried out on a sufficiently large size apparatus, and under conditions such as are to be met with in everyday practice or use. Tests of heat transmission on a single row of tubes, whilst interesting scientifically, cannot be relied on for obtaining coefficients of heat transfer applicable to large batteries or heaters. Research workers also have been handicapped no doubt, by not generally having had available, steam and hot water under very flexible or wide range of pressures and temperatures, so as to cary out tests under the many varying conditions to be met with in actual use. Heat transfer, as is well known, is by conduction and convection and the latter is by far the more important, in considering this matter, in connection with air heaters. Convection is fundamentally a very complicated process. Research workers have now clearly established the fact that air turbulence is one of the most important factors, this being perhaps not fully recognised in the earlier days of research.

Dr. Lander[3] stated in his paper, that a satisfactory theory of turbulence has yet to be found.

In the paper read last year by Griffiths and Awberry[4] before the Institution of Mechanical Engineers, the authors stated that they found in testing plain tube heaters, an increase of 50 per cent. in some cases could be obtained by artificially created turbulence in the air stream. They also stated that they found when testing a bank or battery of tubes, that the heat transmission per square foot of heating surface per degree difference in temperature between the heating medium and the air, varied on the first, second and third rows. After the air has passed the third row of tubes, it seems, as it were, to settle down, and the heat transfer coefficient remains fairly constant.

Another difficulty which arises, is that different formation or geometric arrangements of tubes give different results, so that heaters containing the same amount of heating surface, but having the tubes at different pitch, may give quite different results as regards temperature rise and water gauge.

A theory was advanced some years ago in the United States, that the temperature rise or heat transfer was always proportionate to the water gauge set up by the heater. This, however, is far from being the case as the author found by actual tests on large heaters. One can have two heaters working with practically the same air velocity through the net free area and giving the same temperature rise, but with quite different water gauges, this being due to the different arrangement or design of the heater tubes. It is, however, probably true, as has been stated by Fishenden & Saunders[5] that heat transfer is directly proportional to skin friction. The water gauge, however, set up by a heater, consists of skin friction and turbulence and the latter is a very important item, and varies according to the design of heater. Unfortunately, however, one cannot well separate the one from the other in the reading of water gauge obtained on a heater test.

During recent years, heaters with what is known as extended surface have become exceedingly popular and largely used, due to their comparative cheapness and compactness.

The old cast-iron gilled pipe heaters were really the first of this class of heater to be used, and still are to be had. The more modern type of extended surface or gilled type heater, consists of a copper or steel tube on which a ribbon of metal has been spirally wound and fixed in some manner. Other types have square instead of round gills, which will be mentioned later.

The introduction of these gilled-pipe heaters has rather complicated the question of heat transfer, as it has introduced certain variables which were not present in the older plain tube heaters. The heat transfer per square foot of heating surface per degree difference in temperature will vary with the design, i.e., the depth or size of gill or fin, the spacing of the gills, the thickness and nature of metal used, the method of attaching the gill to the tube so as to obtain good mechanical contact, and to some extent, the diameter of the tube used.

Little scientific data has been published regarding heat transfer with gilled tubes. The American Society of Heating and Ventilating Engineers, however, is now carrying out research work at the Case Laboratory in the United States. A preliminary report has been printed, in their proceedings, of the work already carried out by Messrs. Tuve & McKeeman.[6] This preliminary report points out the necessity of each manufacturer carrying out tests on his own particular design of heater, as no formula can be given as yet for heat transfer which would be applicable to calculate correctly the heating surface required for every duty and every design of heater.

Some interesting information on heat transfer on gilled tubes used for economisers was given in a paper read before the Institute of Fuel a few years ago by Mr. O. Kubalek,[7] and although the conditions are not quite the same, the analogy holds good. Interesting figures were given as to results obtained with plain tubes and gilled tubes and different forms of gills. That paper also stresses what the author wishes to emphasise, that to purchase air heaters or heat exchangers solely on a heating surface basis is not wise, as it is possible to have very large and ineffective gills, and thus show a large amount of heating surface which may not be efficient. The necessity of using the logarithmic mean temperature difference is also mentioned in that paper as errors in the past were sometimes caused through using the arithmetic mean.

Attempts have been made to avoid the use of logarithms, which entail rather difficult calculations, by using what Kubalek calls " correction factors."

The author understands that research work is now being carried out on gilled tubes by Dr. Griffiths at the National Physical Laboratory on similar lines to that carried out on plain tubes, and the results will no doubt be published in due course.

From the foregoing remarks, it should be concluded that with our present information, the purchaser of air heaters will have to rely on the manufacturer complying with the specified requirements as to temperature rise and stating the water gauge set up in the heater offered, as although giving the heating surface included in the heater may be a guide as to what is being offered, it is no real criterion that the heater will be capable of performing the specified duty. The velocity of the air through the net free area should also be stated, for reasons referred to later.

Selection of Heaters.

In selecting a heater it is suggested that the actual size or amount of heating surface required for a specific duty of any make should be left to the actual maker of the heater, who should guarantee the results under the specified conditions.

Purchasers of heaters have now many makes and types from which to choose when using steam or hot water as the heating medium. In the eye of the contractor, price seems in these competitive days to be almost the one and only consideration, but there are many other factors which should be considered in making a decision regarding what is best to instal, which briefly are :—

1. Material used.
2. Weight.
3. Size or space occupied.
4. Velocity.
5. Water gauge set up.
6. Mechanical design.
7. Erection.

(1) *Material.* Heaters are available made of cast-iron, steel or wrought-iron tube and copper gilled tube. Which to use depends mainly on whether corrosion either external or internal is to be feared. The manufacturer of heaters is not usually aware of what the local conditions may be, so the responsibility for deciding what metal is best to use should rest upon the prospective user. As corrosion troubles are sometimes serious some remarks on the subject are made on the matter later.

(2) *Weight.*—This is not of great importance except in the case of heaters which have to be fixed in ducts or supported on light steel structures such as in cinemas, etc.

(3) *Space.*—This is very important in some cases as it is often found that insufficient headroom has been allowed and special or non-standard size heaters have to be provided.

(4) *Velocity Through the Heater.*—This is a most important factor as although high velocities mean high heat transfer, they also mean high friction and water gauge, and also noise. In factory installations, noise is not of great importance, but in public buildings, cinemas, theatres, and such like, it must be guarded against. Too high velocity may also cause vibration of the tubes. There has grown up, during recent years, a practice of makers giving only what is called face or duct velocity, which the author contends is really valueless and misleading, as it is the velocity over the tubes or net free area, that is all important. This so-called face velocity gives no clue as to what the actual velocity over the tubes may be, as this depends upon the design of heater, and varies according to the pitch of the tubes in the heater and, if of the gilled type, the spacing of the gills. As an example, one could obtain a heater with

a face velocity of 500 ft. per minute and a velocity over the tubes of 1,000 ft. per minute and a resistance of 0.25 in. water gauge, or one with the same face velocity and a velocity over the tubes of 2,000 ft. per minute and a water gauge of 1 in. It seems therefore very necessary that the velocity of the air through the net free area or over the tubes should be stated.

(5) *Water Gauge.*—This, as above mentioned, varies with the velocity and should always be considered, as upon it depends the power required to blow or draw the air through the heater, and, of course, the power required varies directly as the water gauge. Different makes or types of heater can be offered for the same duty with widely differing water gauge. High water gauge usually means low price, but the actual user will pay for the increased power taken.

(6) *Mechanical Design.*—There are many points regarding design which ought to be considered in the selection of a heater. First, if tubular heaters and not cast-iron are to be used, the question should be decided as to whether to use plain or gilled-tube type. This depends mainly on whether the air entering the heater is clean or dusty and whether an air filter or air washer is to be used in front of the heater. The plain tube heater is more expensive and takes up more space than the gilled type, but is much less liable to get choked with dust and dirt than any make of gilled-tube heater. For use in textile mills and factories, laundry drying rooms, etc., where particles of yarn or fluff are liable to be drawn into the heater, the plain tube heater is much to be preferred, as a gilled-tube heater used in such atmospheric conditions in course of time becomes so choked with particles of fluff, etc., as to become very inefficient, and it is very difficult to clean, and in process work any interruption to service is a serious matter. For use in connection with plant for hospital operating theatres, photographic paper or film drying and such like, plain tube heaters are also usually specified, as cleanliness and ease of cleaning are all important factors in such installations. Many other kinds of installation should also include plain tube heaters instead of the gilled type.

Having settled the question of whether to use plain or gilled tubes, other important features to consider are the methods of securing the vertical tubes to the headers, the provision for expansion and contraction of the individual tubes, and of the headers themselves.

With copper tubes, this question is even more important as the coefficient of linear expansion is about 50 per cent. higher than that of steel.

Attention should also be paid to the design of heaters as regards the equal distribution of the heating medium so that each section or row of tubes, and also each tube, receives its due share of heating medium. In most modern heaters the steam enters at the top and flows downwards, which is an improvement on the old type of heater with cast-iron base or header, where the steam had to travel up one leg or side and down the other.

The quality and gauge of metal used for the casing of the heater should also be considered, and whether of painted or galvanised sheet. In the more modern gilled-tube heaters, whether copper or steel, pressed-steel encasements are usually supplied which contain either one or two rows of gilled tubes. The older plain tube heaters, usually have galvanised sheet-steel casings with angle-iron flanged ends and suitable stiffeners.

(7) *Erection.*—Some consideration as to ease or otherwise of erection of different types of heaters should be given. The type of casing supplied whether complete with all necessary angles, bolts, etc., and whether connections are included with manifolds for steam and drain should be noted as different manufacturers adopt varied methods regarding what they supply.

Size of Heater.

As previously suggested the actual size of heater required should be left to the manufacturer to calculate from his own test figures on heat transmission with the particular type of heater to be offered.

The formula for this, so far as it goes, is comparatively simple, as given the volume of air and temperature rise required, one easily gets the B.T.U. required per hour, by the simple formula

$$\text{B.T.U.} = \frac{V \times R}{C}$$

V = Volume of air in cubic feet per hour.
R = Rise of temperature in degrees F.
C = Volume of air raised 1° F. by each B.T.U. at 70° F., i.e., 55 cubic feet.

The heating surface required is found by dividing the B.T.U. transmitted per square foot of heating surface into the total B.T.U. required.

In order to calculate the heat transmission per square foot of heating surface it is necessary to know the value of the coefficient K. This being the B.T.U. per hour per square foot per degree difference of temperature. The velocity of the air through the free area of the heater must also be known. The value of K changes according to the velocity. Carrier states that it varies approximately as the two-thirds power of the velocity. Then taking the mean temperature of the air and the mean temperature of the heating medium, the mean average temperature difference is arrived at, and this multiplied by the coefficient K gives the heat transmission per square foot of heating surface. For accurate calculations, as mentioned previously, the logarithmic mean temperature difference should be used instead of the arithmetic mean.

The above formula should not, however, be taken as giving absolutely correct results, as the value of K varies with different designs and types of heaters, and it is mainly for this reason that the author recommends that the responsibility for arriving at the correct amount of heating surface to provide for a specified duty should be left to the manufacturer.

Corrosion.

Previous mention has been made of corrosion in connection with deciding of what metal a heater should be made, and by corrosion is meant internal corrosion rather than external. A paper was read on the subject by Mr. A. C. Pallot[8] before this Institution in 1932, which clearly showed what a very difficult and complex problem it is and how important the matter is to engineers and heating engineers in particular.

To all interested in the subject, a perusal of that paper is recommended.

The responsibility for deciding what metal to use is really one for the chemist and the metallurgist rather than the heating engineer or the heater manufacturer. Trouble is not likely to be experienced with the ordinary heating system where the water is recirculated through the system and little or no make-up is required. Also where the supply is taken from any of the large public undertakings or supply companies, the characteristics of the water being known and peculiarities, if any, of a destructive or corrosive nature can be guarded against. Corrosion troubles seem, however, to be becoming more frequent and particularly where the water supply is obtained from deep wells, and it is in these cases that care should be exercised and expert advice obtained, especially if steam is to be used as the heating medium, as to whether the character of the water is likely to cause corrosion when the steam is condensed. As mentioned in Mr. Pallot's paper, corrosion trouble is very frequently caused by free oxygen ; CO_2 gas may also be present, and even copper tubes will not withstand the effect of some of these gases.

The author would hesitate to express any opinion on the matter so difficult a problem is it in some cases to know what material would be best to employ. The subject is one which calls for further research and it is to be hoped that the Institution may undertake or bring pressure to bear on some of the Government Departments to have further research work carried out. Much has been done in the United States during the last few years on this matter.

I hope there may be some discussion on this, because it is becoming a largely-increasing trouble. The point is that you may get a heating job at some factory where they have had no trouble at all with the boilers, and where they say that the water is all right, and then when you put in a heating plant and use steam from the engine or turbine you have trouble, usually due to the released gases when the steam is condensed. The usual chemical analysis of the water does not help very much, and it is really a matter for an expert to find out what can be done to get rid of those gases. De-aeration is frequently employed, but the whole problem is beyond the competence of the average engineer and is a matter for the chemist and metallurgist to tackle between them. The Americans are doing a great deal more about it than has been done here, because they have had a great deal of trouble. My own idea is that a partial explanation may be as follows. In the past most factories used slow-speed horizontal engines with generous cylinder lubrication, and the condensed steam had a slight amount of oil in it, and this oil, though it reduced the efficiency of the heater, was of use in preventing the occurrence of corrosion. Modern practice, however, is to use much higher steam pressures and to employ turbines or non-lubricated engines, and, although it is good to have oil-free steam, I think it may possibly cause an increase of corrosion trouble. Moreover, as Mr. Pallot points out in the paper to which I have referred,[8] we may also in some cases be having electrolysis taking place due to the earthing of various electrical apparatus, and we do not know what stray currents may be about. That also raises a very complex problem.

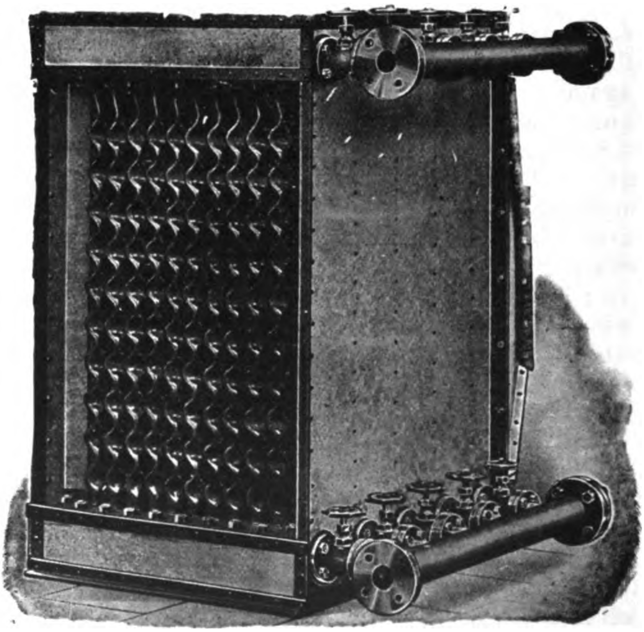


FIG. 1.

Some Types of Heaters.

A solid-drawn steel-tube heater is shown in Fig. 1 made up of "Row" indented tubes, and was referred to in the earlier part of the paper.

The tubes are expanded into steel-tube plates at top and bottom, the tube plates being carried in cast-iron boxes. The header is made up into separate sections; the illustration shows a five-section heater, each section being controlled by a valve on steam and condense.

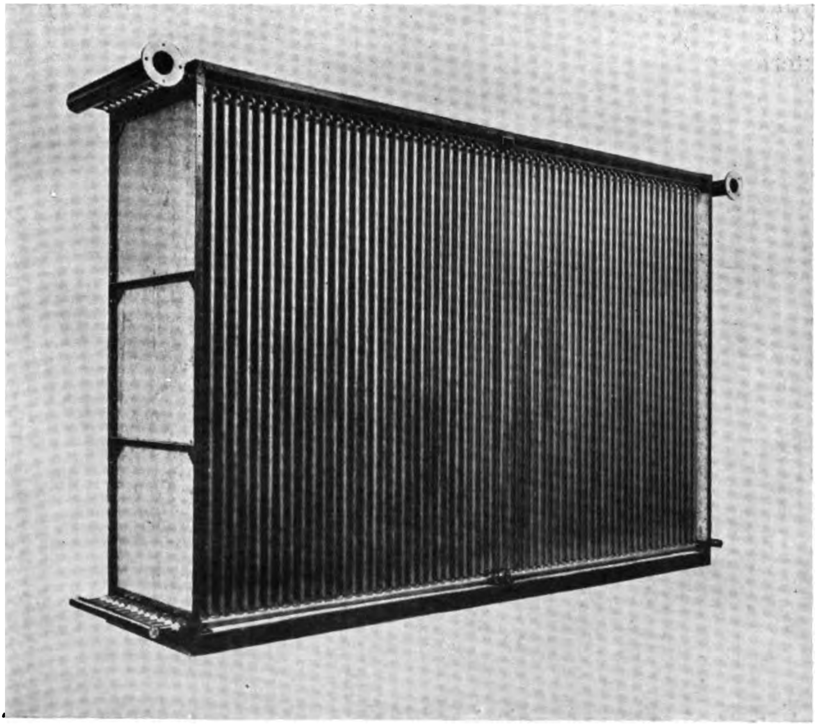


FIG. 2.

A plain tube heater of the Weldex patent design is shown in Fig. 2. This design consists of a number of vertical 1-in. nominal bore steam tubes assembled between steel tubular top and bottom headers to form a complete section or grid, and the method of jointing the vertical tube to the headers is by welding. Instead, however, of the 1-in. tubes being connected directly to the headers, the tube is diminished at the point of the weld to a relatively smaller bore, which in addition to providing flexibility at the point of connection, calibrates the supply of the steam or other heating medium to the respective tubes, thus avoiding short circuiting and ensuring an equal rate of heat transmission throughout the sections.

For high-pressure steam, the top connection of each individual tube takes the form of a miniature expansion-bend in small section weldless tube, and this takes up any unequal expansion in individual tubes, which otherwise might, in time, cause trouble.

The header tubes themselves are correctly proportioned to feed the heating tubes, and the ends of the steam and condense headers of the individual sections are connected to manifold pipes supplied with the battery, by means of a special form of joint. These joints are the only ones in the heater, which are not welded, and being external to the casing, are always accessible.

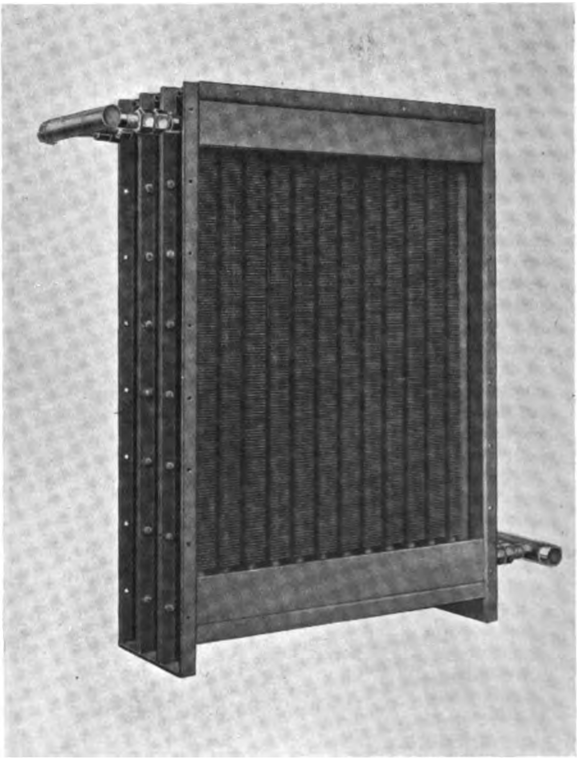


Fig. 3.

Fig. 3 shows a Weldex steel gilled-tube. The design is similar to the plain tube type, mentioned above, as it is of all-welded construction. The gills are square, and embedded into the wall of the

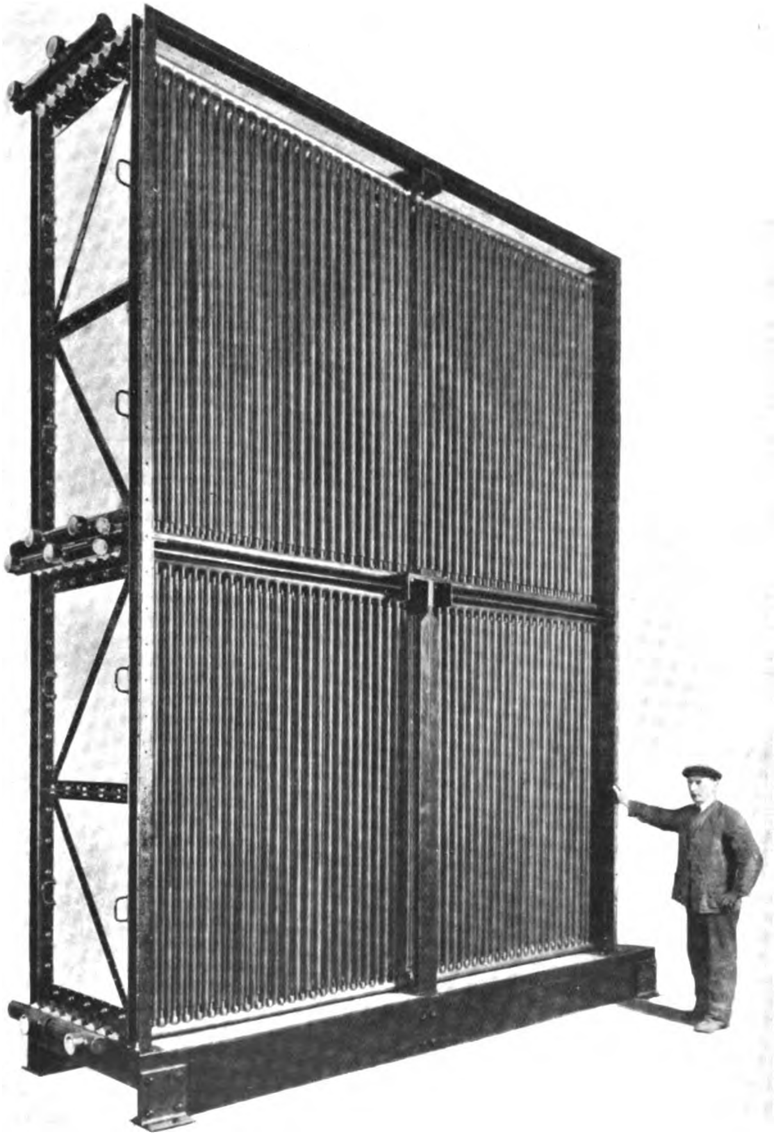


FIG. 4.

tube by a special process, resulting in a heating element of great mechanical strength, and as the gills are in such intimate contact with the wall of the tube the heat transmission is high and the efficiency permanent. It is claimed for this design that it is superior to the wound ribbon type of gill where the contact is dependent upon the tension of winding.

Fig. 4 is from a photograph at the works, of a very large size Weldex heater using hot water as the heating medium. It will be seen that the heater is made in two tiers on account of its size. It is designed to pass 5½ million cubic feet of air per hour. This heater was supplied in connection with Dr. Oscar Faber's scheme for the ventilation and heating of the Bank of England, about which a paper was read to this Institution by Dr. Faber some time ago. It was installed by the heating contractors, and the thanks of the author are tendered to Dr. Faber and to Messrs. Rosser & Russell Ltd., for their permission to publish this illustration.

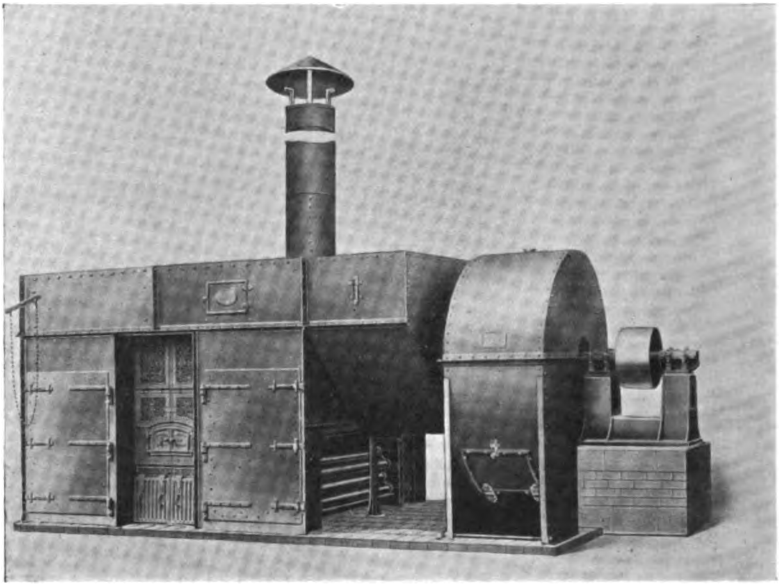


Fig. 5.

Direct-Fired Air Heaters.

This type of heater, as the name implies, imparts the heat units contained in the fuel without the use of an intermediary in the form of steam or hot water ; no boiler or piping, therefore, is required. One of the best-known types is that sold under the "Sirocco" trade mark. Fig. 5 shows what is called the Sirocco multitubular air heater, which consists of a central furnace from the back of which the products of combustion pass into the two smoke chambers at the right- and left-hand side of the furnace—from here the gases are led along the upper rows of horizontal tubes to the front of the heater and then back through the bottom rows to the smoke chamber and thence to the chimney. The cold air is drawn by a fan over the tubes which have been heated by the hot gases. This type of heater is suitable for burning coal, coke or wood, or can be adapted for oil fuel. Fig. 6 shows what is called the vertical flue type

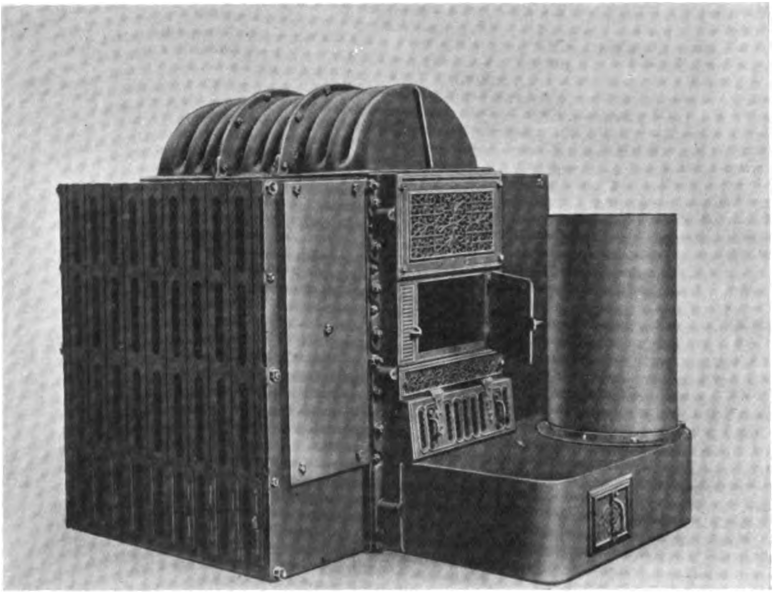


Fig. 6.

Sirocco heater, it being used for rather smaller air volumes and mainly in connection with tea-drying plants. In this design the air is drawn over flat ribbed cast-iron plates at the side of the central furnace. These plates are bolted together in such a manner as to form alternating series of smoke and air flues. These direct-fired heaters are used also for many other drying processes in this country, such as hops and other vegetable products of various kinds. They are very easily operated and can be looked after by unskilled labour.

Gas-Fired Air Heaters.

Gas-fired air heaters are now being used successfully in many different ways. Particularly for obtaining air at high temperature as is required, for instance, in a Turkish bath installation, Fig. 7, and for many drying processes

Gas heaters have also been installed in connection with normal heating and ventilating work either in the form of one main air heater or to localised or booster units inserted in the trunking of the system, as shown in Fig. 8 and Fig. 9.

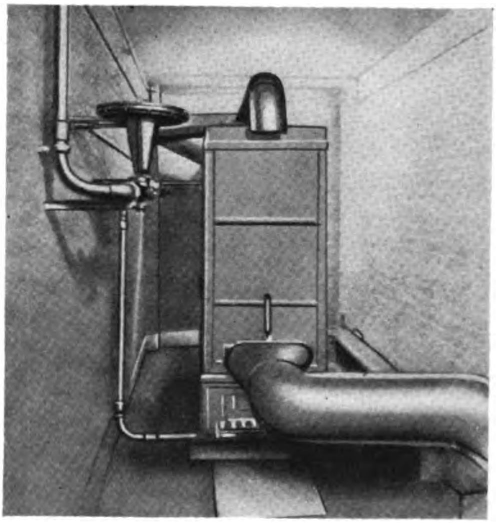


Fig. 7.

The advantages of gas-fired heaters are that no boilers, no steam or water pipes are required, only the necessary gas-supply pipes and vent pipe for the products of combustion.

The control of gas-fired heaters can be fully automatic, using any accepted form of thermostatic control and special safety devices to cut-off the gas if the air flow stops from any cause. One of the great advantages of using gas as the means of providing heated air is the ease and flexibility of control which can be obtained.

Unless steam is available at high pressure, it is difficult to obtain the high air temperatures often required in many drying processes, such as stoving of enamels, etc., and also in the case of Turkish baths before mentioned. The direct application of the gas in the heater makes for efficiency by eliminating boiler and pipe heat losses.

Gas used to be considered too expensive, but with the rebates now being given, at any rate by some of the largest companies in London, to extensive users, and in places such as Bath, where the price has come down to 4d. or 5d. a therm, gas should be considered, as an air-heating medium in certain cases.

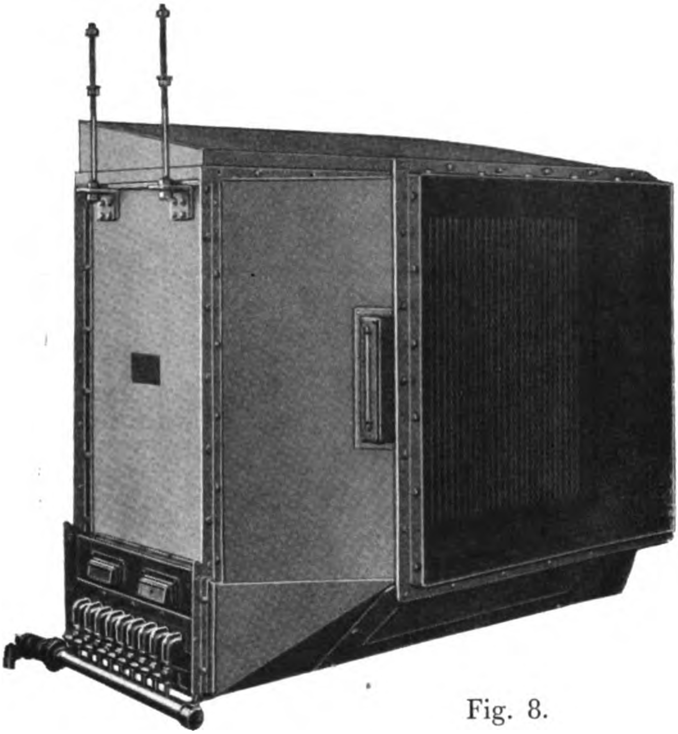


Fig. 8.

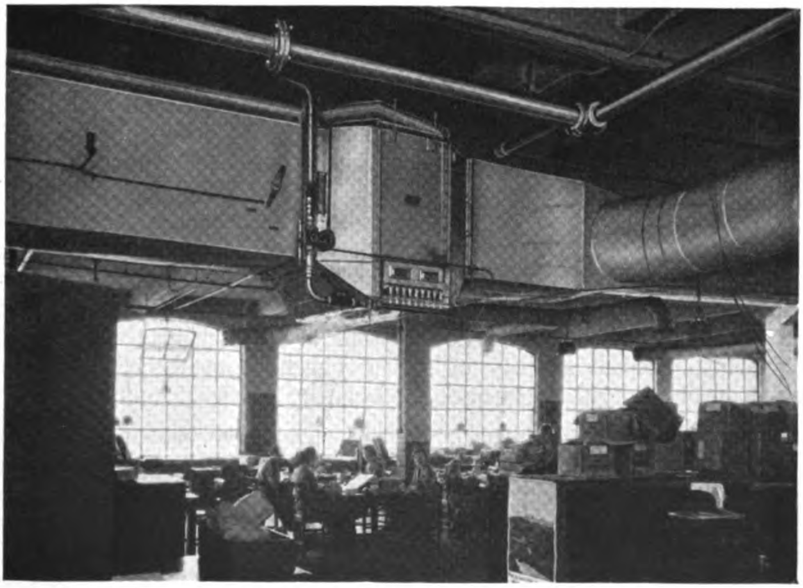


Fig. 9.

Electric Air Heaters.

Of all forms of air heaters the electric is perhaps the simplest and most compact. It can also be very easily controlled either by hand or automatically by thermostat. Various types of heater elements either of the plain or finned type are now on the market. In the paper read before the Institution of Civil Engineers in February, 1929, by Mr. A. H. Barker,[9] particulars of the large heating and ventilating plant designed by him and installed at Messrs. Bourne & Hollingsworth's premises were given. This is, the author believes, one of the largest installations of its kind in the country. Mr. Barker maintained that the special circumstances in this case justified the use of electricity, instead of coal, oil or gas, as the means of obtaining heat. Messrs. Grierson & Betts,[10] in a recent paper read before the Institution of Electrical Engineers, stated that the possibility of obtaining electric current at prices sufficiently low to justify the adoption of electric air heaters for mechanically-ventilated buildings of large size, appears rather remote, though there are cases where, due to convenience or space considerations, the use of electric air heaters may be justified and mentioned, as an instance, the News Theatre in Piccadilly Circus.

I believe electric air heating may also be considered in countries which have water-power. It is possible, where water-power is available in large quantities, to generate current for a very small sum, apart from the capital cost, and in such cases, of course, electric air heaters might be justified. In India they are being used increasingly for tea-drying; the scarcity of fuel there is becoming so serious that, particularly in Assam, where water-power is usually available, electric drying is quite a commercial possibility.

Conclusion.

Finally the author would like to point out that the object of this paper is to show the great developments in the design and manufacture and the extended use of air heaters in this country during the last 25 years.

It is not the object of the paper to provide any new theories or data regarding heat transmission under such conditions, but rather to emphasise the necessity of the prospective purchaser or user looking rather beyond the question of price, and that the maker guarantees the heater offered as capable of performing the specified duty, and the advisability of giving careful consideration to the various points mentioned under the heading "Selection of Heaters."

Acknowledgments.

The thanks of the author are tendered to the following firms for technical information, photographs, etc., of various types of air heaters : Messrs. Davidson & Co. Ltd., The Gas Light & Coke Co., Messrs. Royles Ltd., The Victoria Tube Co. Ltd.

REFERENCES

[1] Willis H. Carrier & F. L. Busey. "Air Conditioning Apparatus." *Am. Soc. Mech. Engrs.*, Dec. 1911.

[2] Harding & Willard. "Mechanical Equipment of Buildings Heating and Ventilation." Vol. I. 1917.

[3] Professor C. H. Lander, M.Inst.C.E. "Modern Methods of Attacking Heat Transmission Problems." *Inst. of Chemical Engrs.* Feb. 1934.

[4] Dr. Ezer Griffiths and J. H. Awberry, B.Sc. "Heat Transfer between Metal Pipes and a Stream of Air." *Inst. of Mech. Engrs.* Dec. 15th, 1933.

[5] Fishenden & Saunders. "The Calculation of Heat Transmission." H.M. Stationery Office, 1932.

[6] G. L. Tuve and C. A. McKeeman. "Heat Transfer from Direct and Extended Surfaces with Forced Circulation." *Am. Soc. of Heating and Ventilating Engineers*, June Meeting 1934.

[7] O. Kubalek, M.Sc. "Fuel Economisers with Special Reference to their Construction Materials and Recent Developments." *Inst. of Fuel.* Jan. 8th, 1930.

[8] A. C. Pallot, B.Sc. "Pipe Corrosion." *Inst. of Heating and Ventilating Engineers.* Mar. 2nd, 1932.

[9] A. H. Barker, B.Sc., etc. "The Electric Heating and Ventilation of Bourne & Hollingsworth's Premises. *Inst. of Civil Engineers*, Paper No. 4704. Feb. 19th, 1929.

[10] R. Grierson and D. Betts. "A Critical Examination of the Present Practice relating to the Electrical Warming and Air Conditioning of, and the Supply of Hot Water to the Larger Buildings." *Inst. of Electrical Engineers.* Dec. 6th, 1934.

DISCUSSION.

Mr. W. E. Fretwell said he congratulated Mr. Fleming Browne on presenting a paper which, while not introducing a great deal of mathematical matter, gave clearly the fundamental principles connected with air heaters for heating, drying and other purposes.

In the first paragraph of the paper, reference was made to air conditioning having been in its infancy a quarter of a century ago. That was true, but to-day air conditioning had made enormous advances not only in connection with ventilation but in regard to all kinds of problems—textiles, foodstuffs and so on. The importance of questions of temperature and humidity was more recognised to-day than ever before.

The author went on to refer to the need for taking the mean logarithmic temperature of the air, and that was true; the arithmetic mean was not correct at all. Reference was then made to the question of heat transfer, which in his personal opinion and in that of many others, bristled with difficulties. One thing which was certain with regard to heat transfer, whether it was the transfer of heat to the air or not, was that the external temperature was an important factor. The potential conduction of heat through the material of the heater itself always exceeded by far the rate at which it could be given off from the cooler surfaces. The introduction of extended surfaces such as gilled tubes, etc., was a recognition of that fact.

The calculation of the transfer of heat from the inside of the tube to the metal itself and from the outside, was difficult. The transfer of heat to the air must depend upon the intimacy of contact of the molecules of air with the tube and upon how long they remained there.

A large amount of research work on heat transfer had been carried out, and none had a greater regard for the value of such work than himself. Unless one was conversant with modern research work in regard to heat transfer, whether with regard to air, water or steam heaters, one could not design a plant with any degree of confidence. On the other hand, the person best able to give the necessary figures on the actual quantitative transfer was, or should be, the manufacturer of the given article.

On the question of plain tubes, from the point of view of cleanliness the plain tube was obviously to be preferred, but it occupied more space and was more expensive. The merit of the gilled tube was the smaller amount of space which it occupied and the lower price at which it could be produced. He had had some trouble, not with gilled-tube air heaters, but with unit heaters installed in dusty factories where such a quantity of dust adhered to the gills that in time the free area of the units were affected, and the effectiveness of the heaters reduced accordingly.

With regard to gas heaters, they had one important advantage so far as their use in Turkish baths were concerned. As was well known, the hottest room in a Turkish bath should be between 220° to 260° F. If steam is to be used for warming the air it had, of course, to be kept at a much higher temperature than that of the air. To keep a stoker on duty at night and at week-ends to maintain the temperature of the Turkish bath is a very costly matter, and it had proved much more economical to instal a gas heater, which automatically maintains the air temperatures at all times.

He would like the author to refer in his reply to the use of superheated steam in connection with air heaters.

Mr. J. W. Cooling said that he thought the author had done very good work in bringing to the notice of members of the Institution the great difficulties which presented themselves in choosing the right type of air heater. The author gave a list of certain points to be considered in the correct selection of heaters, but personally he would have to disagree with that list if the factors were placed in order of merit. To his mind there were three important points to be considered: (1) what he called the heat-transfer efficiency; (2) the noise due to the passage of the air through the heater; and (3) the cleanliness of the heater.

In the section dealing with Heat Transfer the author said: "One can have two heaters working with practically the same air velocity through the net free area and giving the same temperature rise, but with quite different water gauges, this being due to the different arrangement or design of the heater tubes." Personally, he thought that manufacturers, instead of giving a coefficient which stated the number of heat units per square foot per degree temperature difference, should evolve another coefficient which would give the heat transmission in B.T.U. per square foot per degree temperature difference per inch water gauge of resistance through the heater. That would enable users to select heaters much better, because with present ventilating and air-conditioning systems they were increasing in size every day, and there was no doubt that resistance through the heater was a very vital point. Running costs were important, and the fan running costs depended on the resistance through the heater.

It was true that dirt adhered to gilled tubular heaters, and the dirt seemed to adhere to those with a corrugation in them much more than to those with a plain gill. One remark which the author made might lead members to think that if they had an air washer in the system they would not suffer from dirt on the tubes. He could assure them, however, that they would, even with the best air washer that had ever been made, because the air washer let through the kind of dirt which stuck to the tubes, and the only way to stop it was to put in some form of textile or viscous filter.

He had hoped that the author would say something about the famous little heater he persuaded him to make some time ago, fitted with streamline sectional tubes. He was sorry that the author dropped it, because he believed there was something in it. With a circular tube there must be a lot of dead water at the back of the tube, and he believed that with a streamline tube a much better use of the surface of the tube was obtained than with a tube of circular section. There might be difficulties with regard to the cost of construction, but it should be possible to work at higher velocities with a streamline tube, and therefore the size and weight of the heater would come down and the cost would be reduced.

He thought the author might have warned engineers in selecting electric heaters to be careful to compare not the cost of the electric heater with that of another form of heater, but the cost of the electric heater *plus* the switchgear, because he had always found that the switchgear was a fairly heavy item in any electric heater. It was, moreover, very important to interlock the switchgear of the electric heater with the fan switchgear ; otherwise when the fan stopped there was a risk of the heater being burned out.

He would like in conclusion to record his thanks to the author for introducing the subject. He hoped that at some future time the author might be persuaded to collect all the data available relating to different forms of heater and read a paper comparing these different forms of heater on the basis of the coefficient which he (the speaker) had suggested, which brought in the extra term of resistance through the heater.

Mr. T. G. Noble, after thanking the author for his excellent summary of the various types of air heaters, referred to the question of streamline tubes raised by Mr. Cooling. He agreed with Mr. Cooling as to the advantage of having a streamline tube, and was surprised that the author did not refer to the question, since Professor Lander, in the paper quoted by the author, stressed the considerable increase in heat transfer which could be obtained by using a streamline tube. He did not agree, however, with the explanation which Mr. Cooling had given ; he thought it was generally accepted that the difficulty in heat transfer was not on the water side or on the steam side but on the air side, and, if he had the same idea of a streamline tube as Mr. Cooling, he thought the explanation was not that one avoided any dead end on the water side but that by streamlining a tube a greater proportion of the total air resistance was due to skin friction than was the case with the circular tube, where there was a great deal of turbulence. The resultant advantages were obvious : there was greater heat transfer for a given heating surface, or for a given heat transfer a smaller heating surface was required, and one obtained a more compact appliance ; and for a given duty one had a reduced water gauge, or for a given water gauge an increased duty. On the question of noise, perhaps Mr. Cooling would agree that probably the use of a streamline tube would also diminish the noise problem, because the noise was at any rate partly due to air turbulence, which would be reduced by the use of such tubes.

Mr. J. W. Cooling, to correct a misapprehension on Mr. Noble's part, said he had referred rather loosely to dead water behind the tube, but he had in mind the eddying of the air on the back side of the tube.

Mr. T. G. Noble said that in that case he was in complete agreement with Mr. Cooling.

Mr. C. G. Nobbs said that as an electrical engineer he was very interested in the paper because the author enumerated the difficulties which were experienced with apparatus other than electric air heaters. He was sorry to find, however, that the electric air heater was dismissed so briefly in the last paragraph of the paper, and thought that in a few years' time it would be described at the beginning of a paper and not at the end.

There was comparatively little difficulty at all with heat transfer with the electric air heater, although that was apparently one of the great difficulties with other types of heaters. With the electric air heater the B.T.U. must go into the air, the temperature depending purely on the loading, volume and velocity. The water gauge in the case of a properly-designed electric air heater was negligible and he thought it would be generally admitted that there was nothing so flexible as an electric air heater. He would like to suggest to Mr. Cooling that electrically-controlled switchgear need be no more expensive than the control gear of a steam battery or hot-water battery if the latter were asked to do what electricity was asked to do in the control-room. Electrical apparatus was clean, flexible and quick in operation ; with it one could make a building habitable in a few minutes, whereas to start up steam boilers took a very long time indeed.

Mr. Walter Yates said he was glad that the question of turbulence had been raised by the author ; in making heaters it was very necessary to take particular note of that question. The way in which the air went through the heater was exceedingly important, and probably just as important as the amount of surface provided, so that in making a heater it was necessary to have that very definitely in view.

He was also glad that Mr. Cooling mentioned the need for interlocking the electric heater with the fan. Only the other day his firm had a complaint that the electric heater which they had supplied had burned out, and on examination it was found that the attendant had left it going after stopping the fan, so that of course a burn-out was inevitable.

The question of corrosion was a very important and difficult one, and he was sorry that more information was not available with regard to the corrosion of different metals and different methods of making heaters to avoid corrosion. If the author could give any further information on the matter it would be very useful.

There was another matter on which he would welcome any information which the author could give. He had tested several heaters and found cold spots ; the top of the heater might be hot but the bottom might be cold, or the bottom might be hot and the top cold. If the author could explain how that came about it would be very helpful on occasions.

He would like in conclusion to thank the author for the paper, which was a really practical one. The members sometimes welcomed papers containing masses of technical data, but they did like practical papers, and he was sure that many of the members present would have gathered from the present paper, in view of its essentially practical character, information which would be useful to them.

Mr. E. Bernard Darby, after thanking the author for his paper, referred to the question of heat transfer and said he wondered whether all the members knew what ratio heat transfer in air heaters, steam-heated or water-heated, bore to, say, transmitting heat from steam to water. Actually he thought it was only in the neighbourhood of 10 per cent. or less, and in transmitting heat to air, therefore, considerably more surface was required than in calorifier practice.

It was essential that the mean logarithmic temperature should be used ; the arithmetic mean may lead one into great errors. He did not think there was any set relation between the two ; he had never heard of any.

The author referred to a paper read last year by Griffiths and Awberry before the Institution of Mechanical Engineers, in which it was stated that the heat-transfer rate on the first, second and third rows of tubes varied. Personally, he thought that could be explained in the following way. Certain coefficients of transmission were given, but they were only averages within a certain range of temperature, and actually the transmission rate varied with the mean temperature difference. The transmission rate was only an average rate, and therefore the first row of tubes, getting the cooler air, would have a higher transmission rate than the following rows.

Later in the paper the author pointed out how the air velocity affected the heat-transfer rate, and of course that was quite correct, but there was another point with regard to velocity in cases where the air was being heated by the circulation of hot water through the tubes. There again the transmission rate varied according to the velocity of the water going through the tubes, and therefore accelerated circulation gave much better efficiency with the same surface than gravity circulation.

The question of superheated steam had been raised, and he would like to make a few remarks on that subject. He thought that for heat-exchange work generally, and not for air heating only, it was recognised that superheated steam was no help at all, and as a matter of fact was definitely a hindrance to the transmission of heat. It was useful for getting high efficiency out of large steam-turbine plants, etc. The term " superheat " meant that the steam had been heated beyond the saturation temperature corresponding to its particular pressure. Before the steam could be condensed and the latent heat extracted the superheat had first to be removed, or in other words the steam cooled again to the saturation temperature. The transmission value of the tube surface was therefore adversely affected on account of this necessitated preliminary cooling.

Mr. Browne, wisely perhaps, kept away from actual transmission-rate values. These were, the speaker thought, the sole concern of the manufacturer, and dependent upon the particular design of heater. The chief concern of the buyer or user was the performance and durability. He agreed with the author's remarks on the subject of face velocity. It was the velocity through the tube spaces and the resultant water gauge which counted.

It was difficult to say much about construction without criticising the different makes, which would not be at all proper. Generally speaking, however, he thought the present-day heaters were a big improvement on the old ones. In most cases there are separate steam and condense headers, which allowed of easy drainage of the condensate, which was much better than the old arrangement employing U-tubes and a single divided header. The author referred to the superiority of the square gill embedded in the wall of the tube as compared with the wound ribbon type of gill which it was suggested relied solely upon the tension of the winding for its rigidity. This latter contention was wrong at any rate so far as the spirally-wound gilled copper tube was concerned in which the speaker was interested. The ribbon or gill of this was not only wound into a machined groove prepared for it, but the tube metal on either side of the groove was pressed over onto the ribbon by a following tool, ensuring a rigid joint between ribbon and tube, with perfect metallic contact.

The question of corrosion was a difficult one, and he was afraid he could not say very much about it, but he thought it would be generally agreed that most of the corrosion took place at the condensate end of the tube, and a great deal would be done to overcome it if the condensate was got rid of as formed. Quick-acting steam-traps should be put in, or if expansion traps were used there should be a receiver between the condense drain and the trap to allow of complete and continuous drainage of the tubes with no hold-up.

He was surprised to find that the author did not mention the unit heater, although it was widely used at present for factory and workshop heating. No doubt, however, the omission was deliberate because the subject had been dealt with at length in a previous paper.

Mr. John A. Kemsley said that Mr. C. G. Nobbs, in speaking of electric heaters, had mentioned that there was no transmission problem. That sounded a little odd, following on Mr. Cooling's remarks about the importance of interconnecting the fan switchgear with that of the heater. Personally, he thought the electric heater got rid of all the heat which it produced simply because its temperature rose in order to make it do so ; in other words, if the air would not carry away the heat fast enough the temperature of the elements rose. He would have thought that the manufacturer of electric heaters was far more concerned with heat transmission than anyone else, because if he was wrong his heater probably blew up, and that was the end of him !

Mr. W. Ferne said that unfortunately he was not present during the reading of the early part of the paper, and he did not know if the author had mentioned any advantages of copper over steel tubes for heaters and any difference in their coefficients of transmission.

With regard to streamline tubes, Griffiths and Awberry, in their paper before the Institution of Mechanical Engineers, referred to turbulence. As the result of their experiments they came to the conclusion, that the emission from the pipes tested was increased by placing in front of them a sort of trellis-work arrangement which produced turbulence in the air and formed eddy currents round the tubes, thus increasing the heat transmission. They gave a chart showing the difference in transmission with turbulence and without, showing practically double the transmission in the former case. How the findings regarding turbulence and streamline flow were compatible he did not know.

Mr. Robert H. Rowell, dealing with the question of corrosion, said he had had a case some years ago which might be of interest, where rapid corrosion took place on a job heated by steam, the steam supply coming from the central boiler plant of a large colliery. In view of the fact that trouble was likely to arise between the contractors and the owners, two chemists were called in on the one side and a very eminent Doctor of Science on the other, and their reports fortunately coincided ; they were in complete agreement. It was found that the trouble was primarily traceable to an agent which was being employed on the central boiler plant for water softening, and the result was that when an analysis was taken of the condensate it was found that what was coming over and causing the corrosion was not only acids in solution but gases in suspension in the live steam. That to some extent disproved the assumption of an earlier speaker that corrosion would occur only on the condensate end. He thought that information might be helpful.

With regard to the suggested streamlining of the tubes, he thought that in the light of tests which had been made, particularly in automobile racing, undue streamlining of the tubes would defeat the object in view, inasmuch as it would reduce turbulence and reduce skin friction, and an important factor in determining transmission was the amount of skin friction which was set up to secure the desired result, which Mr. Fretwell mentioned, of the closest possible affinity between the molecules of air and the surface. He thought that on research it would be found that in seeking to obtain a still further reduction in water gauge, and consequently in power, a stage would be reached when the plant would actually become inefficient. It was the happy medium which had to be arrived at.

Mr. A. H. Harwood (Visitor), referring to the author's statement that gilled-tube heaters were very difficult to clean, said that he found in the case of air heaters of that type that very few makers made provision for cleaning them when designing the heater. He believed only one maker provided a connection for attaching a steam lance, but such a connection, about ½-in. in diameter, could easily be provided and was very useful for cleaning down the tubes. A heater installed at the intake to the air washer in the case of a large ventilation system usually became very dirty, but the difficulty could be overcome where a steam lance could be used.

He did not think the author had referred to the lagging of heaters, which was very important ; if it was necessary to cut down the heater cost it was essential that it should be lagged.

Some members seemed to be afraid of using electric heaters owing to the danger of burning out, but this was quite a fallacy, In the case of most electric heaters, including that in the News Theatre at Piccadilly Circus mentioned by the author, the heater was definitely interlocked with the fan, so that there was no danger of the heater being left on when air was not passing through it.

Corrosion trouble, of course, was not entirely confined to heaters using steam, but also arose in connection with electric heaters. Corrosion or oxidation of the heater elements was of grave importance, and could sometimes be overcome by using a heating element which was entirely covered by metal. With regard to the corrosion of tubes, he disagreed with the author as to the corrosion being dangerous only to the inside of the tube. He thought that in air heaters, particularly of the gilled variety, the corrosion was worse on the outside, especially when the heater was taking air, the temperature and humidity of which varied very greatly ; it would often be found, he thought, that the gills corroded and fell off and that the outside of the tube was much more greatly damaged than the inner surface. Another point in regard to corrosion was that makers did not use the best materials available. Copper was usually specified. The author mentioned that there was a dearth of information with regard to the corrosion of copper, but personally he did not think that that was altogether the case. Most tube makers to-day had information available from researches in connection with condenser tubes, and most makers now had special alloys which were quite corrosion and erosion proof.

Lastly, he disagreed with those speakers who urged that one should aim at creating a great amount of turbulence to make the heater more efficient. It was better, he thought, to put up with a slightly inefficient heater and aim at streamline motion from the fan discharge right throughout the distribution system to the room.

Mr. E. L. Joselin said that so many speakers in addition to the author had referred in one way or another to the proportion between the heating surface on the steam side and the heating surface on the air side that it would not be introducing anything irrelevant if he reminded the members of something which they all knew very well, an old experiment which was carried out in the 'sixties or 'seventies of the last century by John Fletcher of Warrington. It would be recalled that Fletcher experimented with a gas burner in boiling a kettle. He found that on his burner a 2-pint kettle with an ordinary flat bottom boiled in 350 or 360 seconds. He then covered the bottom of the kettle with a number of pegs or studs and found it boiled in almost exactly half the time. Further experiments which he made gave him this relation between the hot gases from his burner and the cold water on the other side, that the proper ratio between the two surfaces was 2.6. That information was given in one or two of the text-books, from which he personally had culled it, regarding it as something which had a bearing on the problem.

The inside of the heater tubes was not all steam ; it was condensing all the time, and there was water on that side, while outside was air. It was the reverse of the conditions in Fletcher's experiment, but the same sort of argument must hold good to some extent, and one wanted a bigger surface to pick up the heat on the air side than one had to give out the heat on the steam side, or the steam-hot-water side, as in fact it must be. That, he thought, would give some guidance as to how far the gills ought to be carried, to what extent they ought to be increased or decreased.

He did not know whether others were aware of it, but he thought one of the makers of gilled tubes had already put or would soon be putting on the market an oval gilled tube, more or less of stream-line formation. The object, he had been told, was to reduce the water gauge and incidentally to give as big a surface to that tube as a tube a size larger would give if circular. One increased the surface but decreased the volume by departing from the circular form of the tube.

On the question of the coefficient, he had been given a few figures and a graph or two by one of the gilled-tube makers and had tried to compare them with the curves of Carrier and Busey referred to by the author. So far as he was able to deduce similar quantities from the two sides he came to the conclusion that the coefficient K for both circumstances was very similar. The coefficient for a particular air velocity on the Carrier and Busey curve gave a figure, he believed, of 10.6 or 10.7, and the coefficient as deduced from the gilled-tube maker's figures and the graph came to a little over 11 for the same air velocity, i.e., the air velocity between the tubes, not the face velocity. It seemed, therefore, as though the coefficients were somewhat similar.

Mr. Bernard C. Oldham (Visitor) sounded a warning with regard to the use of the logarithmic mean temperature difference. It was essential, he said, when using the coefficient K to know whether it was obtained by tests using the arithmetic or the logarithmic mean. For small temperature differences up to 50° F. there was very little discrepancy between the two ; it was in the higher differences, in the hundreds, that it became of vital importance. Again, if one used in a logarithmic sense a coefficient obtained in an arithmetic sense one could go wide of the mark.

It was interesting to learn of Dr. Griffith's research on gilled tubes, and it was to be hoped that the results would be capable of practical application, because so much research was difficult to apply. Sometimes, in fact, research only verified what had been learnt in practice, instead of giving a lead to practice.

With regard to Mr. Joselin's remarks, one had always to strike a balance between heat collection and heat removal. In the case of steam and air, the condensing film of steam was a great deal more capable of giving up heat than the air was of absorbing it. Again, the height of the steam condensing surface had some part to play. If the water thickness became considerable, it had a much lower coefficient of transmission than when there was only a thin film.

Correction factors were often found to be expedient, but personally he regarded logarithms as preferable and almost as simple to use.

Mr. T. A. Worsdell asked what kind of life was obtained from a gas heater where very considerable quantities of products of combustion were chilled by the air in the dust so that there was bound to be heavy condensation. Any data which could be given as to the life to be obtained from a gas-heated direct heater would be useful.

Mr. W. Dieterichs (Visitor) dealing with the gas-fired air heaters, said that Mr. Worsdell's remarks regarding condensation were quite correct, and in designing gas-fired heaters careful attention must be given to that possibility.

About five years ago an air heater was installed for Turkish-bath purposes, and he had an opportunity of examining the interior thoroughly a few weeks ago, and it appeared to be almost in the same condition as when it was first installed. In a recent case an air heater was designed to give a comparatively low outlet temperature and condensation did occur which was due to attempting to attain too high a thermal efficiency, which with this particular heater was in the region of 85 per cent. It was therefore quite obvious that condensation would take place under these conditions, but no difficulty was experienced when the efficiency was lowered to 75 per cent. There was no need, however, to be unduly alarmed because it was merely a question of design, and it was quite a simple matter to make a gas-fired air heater efficient ; it was rather a question of not going too far in that direction.

He stated that Mr. Fretwell had used a number of the gas-fired air heaters, and should therefore be able to give a good idea as to any troubles which he had experienced regarding condensation and the life of the heaters.

Mr. W. E. Fretwell said he first installed a gas-fired air heater for Turkish baths some ten years ago, and no trouble had so far been experienced as to their useful life.

The President said the discussion had been long and interesting, and the meeting was greatly obliged to all those who had spoken and given their experience. In order to give Mr. Fleming Browne time to reply it would be necessary to bring the debate to a close.

Mr. A. Fleming Browne, in replying to the discussion, said he thought that Mr. Joselin and other speakers had really dealt with most of the points raised by Mr. Fretwell.

With regard to the relation between the area of surface inside and outside the tube, it was given by some makers of copper gilled-tube heaters; as had been mentioned air picked up its heat much more slowly than the steam or water inside the tube gave it up, consequently the area of heating surface outside the tube could be much greater than the area inside, and that was the main reason for using gilled tubes. There was a limit, however, to the amount of gilled surface which could be put on, and at the same time retain efficiency, the question of the velocity over the gills also entered into it.

With the plain-tube heater, as Mr. Fretwell was aware, one did not get the rubbing contact of the air right round the tubes ; if one did, of course one would get a most efficient heater. Dr. Margaret Fishenden in one of her books gave a diagram showing what actually took place. By the use of smoke it was possible to take a photograph showing the actual stream of the gas over the tubes, and that showed that the point of contact on the circular tubes in question was a comparatively small arc.

With regard to units getting dusty, he did not want to enter on any discussion of unit heaters, because that had been the subject of a very good paper presented to the Institution by Mr. W. P. Ollett a year ago, and a good paper had been read before the Associate Members' and Graduates Section on the same subject. Anyone reading those two papers would find that they contained a great deal of useful information. It was difficult not to have units of the gilled type of surface if they were to be suspended from the ceiling, because the plain tube was so heavy and expensive. It certainly kept much cleaner, but there were drawbacks to it. One of the oldest of unit heaters was the Stanlock, which was a plain-tube heater sitting on the floor, and a very good unit heater in its time. He did not think there was any trouble with dust so far as the tubes of that unit were concerned, but it had now been superseded by a light gilled copper unit suspended from the ceiling.

Mr. Fretwell also referred to the very difficult subject of superheating, which had been dealt with in a paper by Mr. Phillips, who was very eloquent on the subject of superheating, read before the Institution a year or two ago on the private *versus* public generation of electricity. On that occasion he had put the same question which had now been put to him. Superheating, as Mr. Darby had said, was no good to the heater manufacturer or user ; it was necessary to get rid of the superheat before one could get the heat into the air, and that was a very great disadvantage. Unfortunately, one was often asked to supply heaters to a factory and informed at the last moment " We have superheated steam, but that will be all right ; it is hotter than saturated steam." It was difficult to explain to the factory manager that it would not be possible to get more heat into the air. With superheated steam one had an expanded gas, so that in a certain length of tube one had fewer B.T.U. than with saturated steam ; there were fewer heat units in a given cubic space. Moreover, as Mr. Darby pointed out, condensation did not occur until the steam got to the saturation point. The higher temperature, in addition, caused greater expansion and contraction of the tubes, and that had to be guarded against. His experience was that quite a moderate degree of superheat reduced the air temperature instead of increasing it. One could attempt to get the same results as with saturated steam by adding a certain amount of heating surface to the heater and more or less trusting to luck to get the desired final temperature to the air, but it was uncertain, and in fact superheating was a bugbear to the heater manufacturer. Very little information was available on the subject of how much extra heating surface was necessary. The steam came down a vertical tube, and as it travelled down it gradually became saturated, but no one knew how far it had come down the tube when that happened, so that the whole problem was very difficult, and for air heating the less the superheat the better.

Mr. Cooling commented on the order in which the various factors to be considered in selecting an air heater were given. Personally, he had not intended to put them in any order of merit, and he put the material used first because it was the point which had to be settled first, not because he regarded it as the most important. He agreed with what Mr. Cooling had said as to the order of merit.

With regard to Mr. Cooling's point about heat transmission according to water gauge, possibly something might be done on those lines, but it would require a great deal of working out, and unfortunately most people who were not going to live with the plant insisted on going in for high water-gauge plant because it was cheaper, and the running cost was hardly considered at all. The user should always consider what power the fan would take, but at present he was afraid that the firm who offered the high velocity, high water-gauge heater, which was usually considerably cheaper, got the order. He appreciated Mr. Cooling's point, however, and the matter might be considered and perhaps alternatives given in getting out a catalogue. There was also the question of noise ; one could not have, as a rule, high velocity, high water-gauge and silence.

He had forgotten about the experimental oval tube until Mr. Cooling reminded him of it. His firm had made and tested an oval-tube heater, and it was very efficient and could be worked at a high velocity. The trouble was on the mechanical side ; it was costly, and it was difficult to get the oval tubes. There was practically only one firm which could produce them of the right streamline shape. The tests carried out were not very elaborate, but the results were good from the heat transmission point of view. There was a high final temperature with a high velocity and a low expenditure of power, and the degree of silence was very satisfactory, but the mechanical difficulties were great, because it was impossible to screw an oval tube into anything and it was not easy to attach it to any form of header. He imagined also that it was rather difficult to weld oval tubes. The firm with which he was connected did do it, but they said the mechanical difficulties were great, and they did not think that it was a commercial proposition ; they were afraid that the advantages of the oval tube would be outweighed by the increased cost, and the idea was dropped, and he did not know whether it would be resuscitated. One obtained the rubbing effect on practically the whole of the tube, instead of on only a small arc as with the circular tube.

With regard to electric heaters, he did not know much about the cost of switchgear, but was interested to hear that it was an important item from the point of view of cost and sometimes deterred people from using electric heaters. Mr. Nobbs also mentioned electric heaters, and personally he agreed that they had very many advantages. Mr. Nobbs seemed to think the switchgear was not a very costly item. He himself had no figures for the cost of electric heaters or switchgear, but judging from the discussions which had taken place in various Institutions and from the paper by Grierson and Betts before the Institution of Electrical Engineers, it would appear that electric heaters could not be considered as universally applicable unless current was about half its present price, or at any rate very cheap indeed. He would not like to fix a figure, but a discussion had been going on in the *Electrical Review* with regard to electric heating and the paper by Grierson and Betts, and members would see there the different views expressed as to the cost per unit which would justify the use of electric air heaters. To warm 30,000 or 40,000 cu. ft. of air in a large cinema even from 30° F. to 65° F. or 70° F. was a fairly heavy electrical load. If he had dealt with electric heaters in a brief paragraph it was not because he did not recognise their advantages or because he did not think they were efficient, but he had no illustrations of them, and it was evident that their running cost was a very important item.

Mr. Yates referred to turbulence, and that was a very important point. One could have too much turbulence, and it was necessary to strike the happy mean and to have a moderately turbulent heater which would give good efficiency without setting up an unnecessarily high water gauge. It was a question of good design and experiment.

His experience of cold spots was that they were usually due to some form of air-lock occurring. They were occasionally found, but usually if air-relief cocks were provided the trouble could be eliminated.

Mr. Darby referred to the varying efficiency of the rows of tubes. Dr. Griffiths, in his experiments at the National Physical Laboratory, showed that there was something beyond the fact that the total heat transmission per row varied. It was well known, of course, that the first row did more work, and the transmission of the rows of tubes kept diminishing as the temperature difference between the heating medium and the air grew less. Dr. Griffiths found that there was a peculiar variation between the first, second and third rows, and that it was a question of turbulence, because he found that by putting an agitator in front of the first row of tubes he very greatly increased the efficiency of that row. Dr. Griffiths' experiments at the National Physical Laboratory were well worth studying ; they brought out very well the peculiar effect of turbulence on the first three rows, which effect then diminished. Heat transference depended, of course, on the degree difference, but the coefficient of the first three rows differed from that of the remainder.

Trapping correctly would do something to relieve corrosion, but it did not get over the problem of the corrosion on the condense. If the condense pipes could be kept always full of water there would be less corrosion ; it was when they were half empty that the corrosion effect was at its worst. If the condense line was open to the atmosphere in any way the corrosion effect was very bad.

With regard to Mr. Darby's remarks regarding spirally-wound copper gilled tube, he quite agreed that the type described where the ribbon of metal is actually embedded into the tube made a first-class job, and he had a sample piece of that type of tube which Mr. Darby had kindly sent him. That, however, was not the type of tube he had in mind when he referred to the superiority of the square-gill tube with the gills embedded in the wall of the tube.

Mr. Ferne referred to copper and steel. Copper had somewhat a higher coefficient of heat transference than steel. The difference between the two was largely a question of cost, and there were circumstances in which copper had advantages and circumstances where it was advantageous to use steel. It all depended on the conditions.

He had been very interested in Mr. Rowell's remarks with regard to corrosion and water softening, and agreed that corrosion had occurred where water-softening plant had been put in. Too often when such plants were installed no trouble was taken to analyse the results. The boilers might be all right, but one might get trouble with the condense from the acids and gases, and the difficulty was that one did not quite know when it was going to occur.

There might be two similar plants close to one another, and there might be trouble at one and not at the other. He knew of two large paper mills with heaters doing exactly the same job, both using well-water and within a quarter of a mile of each other. Exhaust steam was used. In one case there was no trouble with condense pipes or heaters, and in the other trouble did occur. He could find no explanation of that; the conditions seemed to be the same, but there must be something in the well-water to cause the difference, or some other local cause, though it was very hard to see what it could be. In the second case the trouble was overcome by deærating the condense water, after obtaining the advice of expert chemists.

He agreed with Mr. Harwood that it was a very good idea to have cleaning appliances provided for the gilled-tube heaters; it saved a great deal of trouble. One did not get much trouble with two or three rows of tube, but it was experienced with very deep heaters for drying work, and they were more difficult to get at. He was also interested in Mr. Harwood's remarks about electric heaters and corrosion; he had not been aware that they were so liable to it. It must be a rather serious problem. Mr. Harwood did not seem to think that there was much trouble from the corrosion of copper tubes on the inside. At one time he himself held that view, but cases did occur where the copper was attacked by released gases, and in some instances the interior of the tube had been eaten away. It was necessary in such cases for chemists to analyse the condense and the conditions generally and to make tests; he did not think it was a matter for the engineer. The only alloy he had heard recommended as almost infallible was cupro-nickel, and the high cost of that ruled it out for commercial use; but he was told by experts that it was the best anti-corrosive metal.

It was interesting to hear that Mr. Joselin found no great error with the Carrier curve, even when using it with gilled tubes. Probably with an efficient gilled tube it would not be very far out, although with an inefficient one it might be. He had found it correct for plain-tube heaters when one took the logarithmic mean for calculating the heating surface.

Mr. Oldham had referred to the mean temperature difference question, and the use of the logarithmic mean. He was very glad he had done so, and he quite agreed with his remarks, and he thought that Mr. Oldham had put the matter more correctly than he, the author, had done or tried to do.

He also agreed with Mr. Oldham's remarks about striking a heat balance between heat collection and heat removal. This was really one of the important details in heater design.

He had no experience himself of the life of gas heaters, but according to Mr. Dieterichs it was good, provided one did not reduce the flue gas to too low a point; and, of course, the same was true with gas-fired boilers. With some gas-fired boilers he imagined it would be possible to reduce the temperature to too low a point and cause corrosion, and with steel chimneys and induced-draught fans with too low a temperature corrosion occurred.

Mr. C. R. Allensby proposed a vote of thanks to Mr. Fleming Browne for his valuable paper. Mr. Fleming Browne, he said, was an authority on the subject with which he had dealt, and his paper had given rise to a very interesting discussion and, together with that discussion, would be most valuable for reference purposes when printed in the *Journal.*

The vote of thanks was carried by acclamation, and, Mr. Fleming Browne having briefly responded, the proceedings then terminated.

I.H.V.E. SCHOLARSHIP

To foster the Technical Education of Operatives.

Title.—The Institution of Heating and Ventilating Engineers Operatives' Scholarship.

Value.—Five guineas per annum for three years.

The scholarship will be available to apprentices, mates and fitters engaged in the heating and ventilating engineering industry, who are over 17 and under 21 years of age on May 1st of the year of the examination.

Selected Candidates will be required to sit for an examination based on the Institution examination for admission to Graduateship.

The final Award will be made by the Entrance Examinations Board on the results of the examination and the personal qualifications of the candidates.

Continuation.—The continuation of the Scholarship for the second and third years is conditional upon (*a*) reports of progress from the Technical Institute and from the Employer and (*b*) the holder still being engaged in the heating and ventilating industry.

Application Forms may be obtained from the Secretary of the Institution of Heating and Ventilating Engineers, and must be returned before March 19th.

THE GLOBE THERMOMETER IN STUDIES OF HEATING AND VENTILATION

By T. BEDFORD, Ph.D. and C. G. WARNER, B.Sc.

Investigators to the Industrial Health Research Board.

The Globe Thermometer.

SINCE the time of John Leslie various observers have used blackened spheres as indicators of radiant heat, but these have generally been filled with hot water, or otherwise heated.

Aitken (1887) advocated the use of a blackened, hollow sphere of thin sheet metal, having a thermometer fitted to it with its bulb in the centre. He refers to readings with globes 15 and 40 cm. in diameter, and mentions that the size of the ball, if not too small, does not seem to affect the readings much.

The globe thermometer, introduced by Vernon, is very similar to the globe used by Aitken. It consists of a hollow 6-in. copper sphere, coated with matt black paint, and containing an ordinary thermometer with its bulb at the centre of the sphere. Such copper globes are sold for use on ball valves, and it is only necessary to solder on to one of these a short tube to hold a cork pierced by the thermometer.

There is no provision for heating the instrument ; its temperature depends solely on the environment in which it is placed. If the surfaces which surround the globe are warmer than the air, the temperature recorded by the thermometer inside the globe will be above air temperature ; and, conversely, with walls and other surroundings cooler than air, the globe thermometer temperature will be below air temperature. Vernon (1932) has shown that the globe reaches approximate equilibrium with its surroundings in about 15 min.

Both Aitken and Vernon introduced their globes as indicators of the effects of radiant heat on human comfort. This use of the instrument will be discussed in a later section. It is first desirable that the influence of radiation and convection on globe thermometer readings should be described.

When the globe thermometer is in equilibrium with its environment the effects of radiation and convection balance each other.

$$H_r = H_c \qquad . \quad . \quad . \quad \text{(i)},$$

where H_r is the heat gain (or loss) by radiation ; and H_c is the heat

---

Abstract from *The Journal of Hygiene*, Vol. 34, No. 4.

loss (or gain) by convection. By Stefan's law, the radiation gain may be expressed by the equation

$$H_r = E.\sigma \quad (T_s^4 - T_g^4) \quad . \quad . \quad . \qquad \text{(ii)},$$

where T_s is the absolute temperature of the surrounding surfaces, T_g is the absolute temperature of the globe surface, E is a numerical constant depending on the emissivity of the globe, and σ is Stefan's constant.

For a surface painted matt black the value of E is about 0.95. Using absolute temperatures on the Fahrenheit scale, and taking the value of σ as 1.73×10^{-9} (Fishenden and Saunders, 1932, p. 12), the value of H_r is expressed in B.T.U. per sq. ft. per hour by

$$H_r = 0.95 \times 1.73 \times 10^{9} \quad (T_s^4 - T_g^4) \quad . \quad . \qquad \text{(iii)}.$$

The equation for H_c, the convection loss, was obtained from a series of experiments in which a 6-in. copper globe, filled with hot water, was allowed to cool in air currents of known velocity.

Convection Loss from a Heated Sphere : The radiation loss from the globe was calculated from equation (iii), and when this was subtracted from the total measured heat loss the remainder gave the convection loss.

As a check on the results thus obtained, further cooling experiments were made on a similar globe which had been silver-plated. Thermopile observations showed that this silver surface had an emissivity of about 8½ per cent., so in the experiments with this globe the radiation loss was calculated by putting E equal to 0.085.

It was found that the convection loss was proportional to the square root of the air velocity, and to the difference between the temperatures of the globe and of the air. When v is the air velocity in feet per minute, t_g is the temperature of the globe, and t_a that of the air (both in ° F.), the convection loss is given by

$$H_c = 0.169 \sqrt{v}\,(t_g - t_a) \quad . \quad . \quad . \qquad \text{(iv)}.$$

Estimation of Radiant Heat by Means of the Globe Thermometer.

In equations (iii) and (iv) the effects of radiation and convection on a 6-in. blackened copper sphere have been described. The heat balance of equation (i) can now be written

$$0.95 \times 1.73 \times 10^{-9}\,(T_s^4 - T_g^4) = 0.169 \sqrt{v}\,(t_g - t_a) \quad . \qquad \text{(v)}.$$

Combining the constants and transposing, we may write

$$T_s^4 \times 10^{-9} = T_g^4 \times 10^{-9} + 0.1028 \sqrt{v}\,(t_g - t_a) \quad . \qquad \text{(vi)}.$$

all temperatures being expressed in the Fahrenheit scale, and the air velocity in feet per minute.

If kata-thermometer observations are taken in conjunction with readings of the globe thermometer it is possible to calculate the radiation from the surrounding surfaces by applying equation (vi), for the air velocity can be calculated from the kata-thermometer readings. The value T_g represents what has already been described as the mean black body temperature, and the radiation intensity in B.T.U. per sq. ft. per hour is readily calculated.

These radiation values refer to a spherical body placed at the observation point. The mean radiation thus ascertained is that from the sphere surrounding the globe thermometer, and since the area projected by the globe is the same in all directions, the mean radiation value is not influenced by the direction from which radiation reaches the globe.

For the purpose of testing the reliability of estimating radiation we have made use of observations made by us in a recent investigation in factories with various systems of heating and ventilation. At each observation position readings of a silvered kata-thermometer (Bedford and Warner, 1933) and of a globe thermometer were taken, and the mean radiation was measured by means of a Moll thermopile. Air temperatures were measured by means of a mercury thermometer, screened with aluminium foil. The air velocity was calculated from the kata-thermometer and air temperature observations. From these data it was possible to calculate the radiation, using equation (vi), and, to test the accuracy of the method, the direct thermopile measurements being taken as standard.

For a total of 221 sets of observations the mean error of estimation of radiation intensity was 1.2 B.T.U. per sq. ft. per hour, or, in terms of mean black body temperature, the average error was only 1.2° F.

The foregoing observations appear to justify the conclusion that the globe thermometer is a practical instrument for the estimation of radiant heat.

Estimation of Equivalent Temperature.

The fact that the globe thermometer yields a reliable estimate of radiation suggested that this instrument might be used with the kata-thermometer for estimating equivalent temperature.

It was first necessary that we should have some information as to the separate effects of radiation and air movement on the heat loss from the eupatheoscope. No equation relating radiation and convection in this way has been recorded, but from a few data published by Dufton (1930, 1933) it has been possible to estimate an equation which seems to give fairly good results. This equation is

Equivalent temperature

$$= 30 + 0.6t_g - (75 - t_a)\,(0.4 + 0.07\sqrt{v}) \quad . \qquad \text{(vii).}$$

where t_a is the air temperature in ° F.;

t_g is the mean black body temperature in ° F.; and

v is the air velocity in feet per minute.

From the results of other workers, cited by Fishenden and Saunders (1932), it would appear that the index of v should be nearer 0.7

than the value 0.5 used in the equation (vii), but, with low velocities such as those commonly met with in ordinary buildings, no serious error is introduced by using $\sqrt{v}$.

Using the notation given in the last paragraph, and putting t_g for the globe thermometer reading, we have, as a close approximation to equation (v),

$$t_s = t_g + 0.169 \sqrt{v}\,(t_g - t_a) \qquad . \quad . \qquad \text{(viii)}.$$

Substituting for t_s in equation (vii), we have

Equivalent temperature

$$= 0.4t_a + 0.6t_g + \sqrt{v}\,(0.101t_g - 0.031t_a - 5.25) \quad . \qquad \text{(ix)}.$$

Under experimental conditions Dufton's estimates of equivalent temperature from kata-thermometer readings had a mean error of 0.82° F. In the fifty-nine sets of observations in which we were able to compare kata-thermometer estimates against eupatheoscope readings, the average error was found to be 1.22° F. When it is remembered that these observations were made in factories where the conditions were subject to variation, this result must be regarded as very satisfactory. For the same group of observations we have estimated equivalent temperatures from globe thermometer readings. Compared with the corresponding eupatheoscope readings, these estimates had a mean error of 1.08° F. Altogether we had 100 eupatheoscope readings with which to compare globe thermometer estimates of equivalent temperature, and over this group the mean error of estimation was 1.18° F.

Our estimates of equivalent temperature from globe thermometer readings were slightly more accurate than those calculated from readings of 75° kata-thermometers.

A possible source of error in the estimation of equivalent temperature lies in the fact that the globe thermometer takes no account of the direction of radiation.

This source of error in the estimation of equivalent temperature is only likely to be of importance where there is considerable difference between the horizontal and vertical components of the radiation.

Globe Thermometer as an Index of Comfort.

Vernon introduced his globe thermometer as a means of indicating the combined effects of radiation and convection as they influence the human body. The temperature recorded by the globe thermometer, which we have referred to simply as the " globe thermometer temperature," is termed by Vernon (1932) the " radiation-convection-temperature," and the excess (or deficit) of the globe thermometer temperature over the air temperature is termed by him the " effectual radiation temperature." Vernon claims that this excess or deficit indicates the " effectual radiation " to which the human body is subjected (1932, p. 96). This claim is not justified, for, as Aitken and Vernon (1932, p. 100) themselves have shown, and as we have demonstrated in this paper, under constant conditions of radiation and air temperature the temperature of the globe thermometer is much influenced by air movement. Therefore unless allowance is made for the effects of air movement the globe thermometer cannot be used to measure radiation, but only to indicate whether the mean radiant temperature is above or below air temperature.

Under calm air conditions (air velocity 12-20 ft. per min.) Vernon found that his subjects were comfortable when the globe thermometer temperature was about 62° F., even though the air temperature ranged from 49.3 to 61.7° F. It would appear from these data that with the low velocities which are generally found under ordinary industrial conditions, the globe thermometer reading is a good index of comfort. When there is any appreciable draught, however, the globe thermometer fails. For instance, when Vernon's subjects, wearing dark clothing, sat out of doors exposed to the sun's radiation they were comfortable with globe thermometer temperatures of 69.5-78.3° F. instead of the 62° F. found to be comfortable indoors. The air velocity out of doors was 93-275 ft. per min., as compared with 12-20 ft. per min. in the indoor observations.

In order to allow for this effect of wind, Vernon calculated corrected kata-thermometer cooling powers, using globe thermometer temperatures instead of shade air temperatures. These corrections make too much allowance for air movement, for out of doors Vernon's subjects were comfortable with corrected cooling powers of 7.3-8.8, while indoors they required a cooling power of only 6.

By itself the globe thermometer is inadequate as an index of the thermal environment. For example, when the air and surrounding surfaces are at the same temperature, the globe thermometer will record air temperature whatever the air velocity. Again, if the surroundings are cooler than the air, the globe thermometer reading will be below air temperature, but with air temperature and radiation constant the temperature of the globe will approach more nearly to that of the air as the air velocity increases. Thus, of two environments, that which would cause the greater cooling of the human body would give the higher temperature reading on the globe thermometer.

Conclusions.

The considerations set out in the last section lead to the conclusion that readings of the globe thermometer taken alone are unreliable as indications of the combined effects of the thermal environment on human comfort.

It has been shown, however, that if in addition to globe thermometer readings the air temperature and the cooling power of the silvered kata-thermometer are determined, much valuable information can be obtained. Such observations are readily made, and from them one can ascertain with considerable accuracy :

(*a*) the equivalent temperature ;
(*b*) the air velocity ;
(*c*) the mean radiation intensity (or the mean black body temperature) ; and
(*d*) the cooling power of the ordinary kata-thermometer.

Of these data (*a*) and (*c*) can be calculated by the methods described in this paper ; (*b*) is calculated from the appropriate equation given by us in a previous paper (1933) ; and by using (*c*) one can determine (*d*) from data set out in that paper.

Thus, in addition to obtaining a reliable estimate of the equivalent temperature, one is also enabled to assess the thermal factors which go to make up that combined measure. This is an advantage when the equivalent temperature shows any departure from the accepted standard of comfort, for information is then available which will serve to indicate the direction in which a remedy should be sought.

In this paper we have advocated the use of silvered kata-thermometers for the measurement of air velocities. It has been shown by us (1933) that, where the surroundings are at a temperature much different from that of the air, estimates of air velocity made from readings of the ordinary kata-thermometer are subject to considerable error.

The results of this study demonstrate the utility of the globe thermometer, and suggest that it should be of considerable value in studies of heating and ventilation.

HEATING AND VENTILATING INDEX

Air. 533·1

Nature of Ions in Air and their Possible Physiological Effects. Leonard B. Loeb. 4 pp. Dealing with the question of electrical carriers in gases and their influence in air conditioning, which the author considers absolutely negligible : *Heating, Piping and Air Conditioning*, U.S.A., October 1934.

Ventilators. 697·9

The Ventilating Effect of a Slotted Cylinder. Huber O. Croft and Theodore R. Thoren. 4½ pp., 11 illus. Describing experiments to determine ventilating effect of different proportioned slots : *Heating, Piping and Air Conditioning*, U.S.A., October 1934.

Cooling. 697.96

Night Air Cooling. S. Konzo. 7 pp., 5 illus. Dealing with variation of daily air temperatures, air changes, methods and effectiveness of night air cooling : *American Artisan*, U.S.A., October and November 1934.

Superheated Steam. 621.101.1

High Steam Temperatures Influence on Superheater Tubes. R. Stumper. Dealing with investigations on the influence of steam temperatures above the normal on superheater tubes : *The Fuel Economist*, November 1934.

Lancashire Boilers. 621.184

Improving the Efficiency of Lancashire Boiler Plants. 6¼ pp., 3 illus. Dealing with combustion efficiency, importance of adequate draught, mechanical stokers, heat transfer and recovery and feed water treatment : *The Fuel Economist*, November 1934.

Warm-Air Heating. 697.9

Heat Loss from Basement Pipes. J. Donald Kroeker. 3 pp., 3 illus. Dealing with heat loss from ducts, chart of temperature drop and how to use it : *American Artisan*, U.S.A., November 1934.

Electric Motors. 621.313

Selection of Motors for Air Conditioning. Oliver S. Imes. 4 pp., 3 illus. Dealing with air conditioning and heating systems, types of motors and selecting the proper motor : *Heating, Piping and Air Conditioning*, U.S.A., November 1934.

Unit Coolers. 697.96

Study of Unit Room Coolers in the Research Residence. A. P. Kratz, M. K. Fahnestock and S. Konzo. 6½ pp., 8 illus. Describing investigation on operation and control of unit room coolers and their performance : *Heating, Piping and Air Conditioning*, U.S.A., November 1934.

Mechanical Stokers. 621.183.6

Mechanical Firing for Small Steam Boilers. Chas. F. Wade. 5¾ pp., illus. Review of developments that have taken place in applying mechanical stoking to small boilers : *The Steam Engineer*, December 1934.

Hot-Water Heating. 697.4

Temperature Drop on the One Pipe System. S. P. Clementson. 2 pp., 1 illus. Describing method of calculating temperature drop and radiator connections for one pipe systems : *Heating and Ventilating Engineer*, November 1934.

ABSTRACTS

Baking Ovens. 641

It may be shown theoretically that about 240 B.T.U. are required to bake 1 lb. of bread. Naturally, this figure is not reached in practice. Electric bake ovens have been installed which show a heat consumption of about 275 B.T.U. per lb. of bread baked. At usual electric rates this is extremely high-cost heat. Gas-heated ovens under average circumstances use about 1 cu. ft. of 550 B.T.U. gas per pound of bread, although very carefully constructed ovens have shown consumptions as low as 350 B.T.U. per pound of bread. Oil-fired ovens show consumptions in the neighbourhood of 1,000 B.T.U. per lb. Coal-burning, hand-fired ovens produce about 8 lb. of bread per lb. of coal under average conditions, but in exceptional cases with large ovens and watchful attendants combined with good oven insulation, 16 lb. of bread can be baked per pound of coal. A figure of 850 to 950 B.T.U. per lb. of bread baked can be taken for estimating purposes. Stokers can be relied upon to bake 1 lb. of bread with an expenditure of from 550 to 650 B.T.U. per lb. It is, therefore, quite patent that, compared to hand firing, stoker-equipped bake ovens may show savings of 33 per cent. or better. The better the oven, the greater will be the fuel saving. Indeed the baking oven needs as good engineering design as the furnace of the best steam boiler. Test results have shown that an overall thermal efficiency of stoker and oven of 50 per cent. can be reached. In order to be conservative, though, we can set this efficiency as low as 25 per cent. and take as a working rule : *A stoker-fired bake oven will produce* 1 *lb. of bread with an expenditure of* $^1/_{10}$ *of a pound of coal.* (David Landau, *Heating and Ventilating,* December 1934.)

Clinker Formation. 662.613.1

It is usually stated that coals having ash fusion temperatures below 2,400° F., are clinkering coals and above this figure they are non-clinkering. This is purely an arbitrary dividing line and has little bearing on the question as to whether or not coal will produce clinker when burned. An examination of the ash from a coal furnace will show that, although there may be no clinkers, nearly all of the ash was fused. The only exceptions to this are in cases where the ash was very highly refractory or where the combustion rate was very low. In other words, the fuel-bed temperature is nearly always high enough to fuse the ash. The ash gradually gravitates to the bottom of the fuel-bed and there it is acted upon by two opposed conditions, the radiation of heat downward from the burning fuel-bed and the cooling effect of the combustion air coming up through the grate. If the cooling effect of the air is not sufficient to cool the ash below its fusion temperature, then clinker will result.

Thus it can be seen that, while the possibility of clinker formation is reduced by using a coal of a high ash fusion temperature, it is possible, by using proper precautions, to burn coals with low ash fusion temperatures without clinker. There is no better way known to produce clinker than to close the ashpit doors with a good fire going in the furnace. This shuts off the flow of air through the grate and its cooling effect on the ash is lost. A heavy fire will produce the same result, due to the increased resistance to air flow. If the fire is stirred deeply with the firing tools the ash will be brought up from the grate into the hot fuel-bed, where it will be fused again and clinkers will form. (Thos. G. Estep. *Heating, Piping and Air Conditioning*, December 1934.)

Body Heat. 613

The table shows the relation between the amounts of sensible and latent heat given off by the body under different temperatures of the dry bulb which are room temperatures under which the conditions noted will occur. It will be seen that the sensible heat graduates from 300 B.T.U. per person per hour at 70° F. down to about 50 B.T.U. per person per hour at 95° F., while the latent heat of the moisture or vapour given off ranges from 100 B.T.U. per person per hour at 90° F. up to 340 B.T.U. per person per hour at 95° F. The increase in moisture, of course, is the result of people sweating at the higher temperatures, while the decrease in the sensible heat is due to the temperature of the atmosphere approaching the temperature of the body. When the atmosphere and the body are at the same temperature all radiation will cease if it is assumed that the surrounding walls and objects are at the same temperature. (H. L. Alt. *Domestic Engineering*, U.S.A., November 1934.)

TABLE.
AVERAGE BODY HEAT FOR PERSONS AT REST.

Temperature. (Dry Bulb) Deg. Fahr.	Sensible Heat from Body B.T.U. per hr.	Latent Heat from Body B.T.U. per hr.	Total Heat from Body B.T.U. per hr.
50	438	70	508
55	410	70	480
60	350	70	420
65	338	75	413
70	300	100	400
75	267	133	400
80	215	175	390
85	165	225	390
90	115	275	390
95	50	340	390

(Above table developed from curves of tests given in A.S.H.V.E. 1933 Guide.)

UNIVERSITY OF MICHIGAN
3 9015 07059 1782